4. Health, safety and environment

Lisbon Conference Proceedings 2011, R. Holmberg et al

Research on the safety standards of blasting vibration

L.Q. Tao & Y.L. Yu
Beijing University of Science and Technology,Haidian 100083, Beijing, China
Tao also Beijing General Research Institute of Mining and Metallurgy, Fengtai 100070, Beijing, China

ABSTRACT: Blasting vibration is a very important part in the revision of the PRC National Bureau of Standards (2003) Blasting Safety regulations (GB 6722-2003) where the Blasting Vibration Safety Standard is one of the hottest debates in this process. This paper is focused on three central issues in the revision process: 1) Safety levels based on particle velocity and frequency. 2) Safety levels based on particle velocity and acceleration and 3) Safety levels based on particle velocity; single-component and three-component vector sum. Among them, the discussion on velocity - frequency two-factor of blasting vibration safety criterion has reached a consensus in developed countries, and has already been used in Blasting Safety regulations (GB 6722-2003). Most countries use blasting vibration safety standards based on velocity, but in some special industries, such as China's nuclear power industry, acceleration is used as a criteria. For the selection of single-component and vector sum, the three component vector sum peak particle velocity (actual max) is most consistent with reality. Based on a large number of in-depth and comprehensive comparative studies of related national and international documents, it is recommended that one should select the vector sum peak particle velocity (actual max) as guidance levels for blasting vibration standards.

1. INTRODUCTION

With the applications of blasting technique coming to reality, there are growing concerns about the surrounding environment and construction (structures) implications caused by the blasting. Vibrations, flyrocks, air blast effects, noise and toxic gases are the top five public nuisance of blasting. Among them, blast vibration is considered to be the greatest problem in the neighborhood of a blasting site. With the increasing awareness of environmental protection, blasting vibration safety and environmental requirements are further enhanced and vibrations caused by blasting has become one of the major research topics of blasting.

Currently, the Blasting Safety regulations (GB6722-2003) are being amended in an orderly manner and the blasting vibration safety criterion is one of the hottest debates in the revision process. In this paper, several typical problems in the development process of the blasting vibration safety standards are described and discussed. Based on a large number of in-depth studies and comprehensive comparisons of relevant national and international literature data, some suggestions are made, hopefully, to play a reference role in the revision process of the PRC 'Blasting Vibration Safety Standards'.

2. RESEARCH STATUS

The seismic effect from blasting needs to be predicted, monitored and controlled by the blasting engineer as part of optimizing the job. Explosive energy release is often manifested in two forms: one is the shock waves; the other is the gas expansions. Ground motion waves are generated by the detonations. In the near field shock waves (P-waves) and shear waves (S-waves) are generated with high attenuation characteristics. At longer distances from the source different surface waves are generated and the most important one is the Rayleigh-wave (R-wave) with a low attenuation characteristic. At longer distances, the R-wave is often the only distinguishable wave. When the vibration reaches a certain intensity, it will affect the stability and safety of the surface and underground construction (structures), or even result in the damage of the construction (structures).

For this reason, many researchers have carried out painstaking studies and research searching for an effective safety control of blasting vibrations. The American, E. H. Rockwell (1927) monitored blast vibrations with displacement seismographs and other equipment. Before and after World War II, the Russians, Ostrovsky and Krylov, studied seismic effects caused by various charge concentrations and proposed a corresponding formula. Nicholls *et al*. (1971) released a research report concerning blast vibrations and their impact on buildings. In the same year, G.A. Bollinger (1971) published his monograph 'Blast Vibration Analysis'. In China Zhang Xueliang & Huangshu Tang (1981) issued 'Blasting seismic effect'. These early studies have certain guiding significance in the blasting vibration theory and application. However, with the development of society and its gradually increased blasting operations the requirements of blasting vibration control have increased as earlier studies have been unable to meet the modern requirements of blasting vibration safety control.

At present, many domestic and foreign researchers have carried out extensive and in-depth research and exploration through rock blasting theoretical models, numerical simulation, vibration monitoring, test methods, signal analysis, vibration damage mechanisms, vibration damage criterion, and blast damage surveys, achieved additional theoretical and practical results. However, due to the transient characteristics of the blast vibrations, the complex geology, foundation and condition of the structures etc. the research of blast vibration predictions still have a long way to go.

3. THE DISCUSSION AND SELECTION OF FOCUS ISSUES OF BLASTING VIBRATION SAFETY CRITERION

On the basis of the performed studies of domestic and foreign literatures and of a number of existing national vibration standards the following should be mentioned with regards to the previous mentioned three central issues in the revision process.

3.1 Safety levels based on particle velocity and frequency

Blast vibrations caused by seismic waves, pass through the foundation of a construction (structure). Whether the construction (structure) is damaged or not it is essentially a structural vibration problem. As described, the effect of blast vibration has many variables such as vibration velocity, acceleration, displacement, frequency, etc. Currently there is no unified conclusion. The generally accepted criteria, based on the vibration velocity, seems to be a reliable criterion.

The Swedish Standard SS4604866 (1991) takes into account velocity, frequency, displacement, acceleration, ground condition, types of construction, construction material and blasting activity (time factor). The standards from U.S. Bureau of Mines (Siskind *et al*. 1980), Germany (DIN4150-3, 1999) and Finland introduced particle velocity and frequency in their criteria.

Nowadays most people think that velocity and frequency of the two criterion is necessary. From the physical meaning of analysis, vibration amplitude can represent the velocity. Amplitude and frequency is the basic physical quantities to describe vibration effect. From the vibration response analysis, different foundations and structures have different natural frequencies. Taking into account the resonance effect, vibration criterion should include the frequency parameters. In practice, such problems are often encountered.

For example in Shenzhen, quarry blasts repeatedly

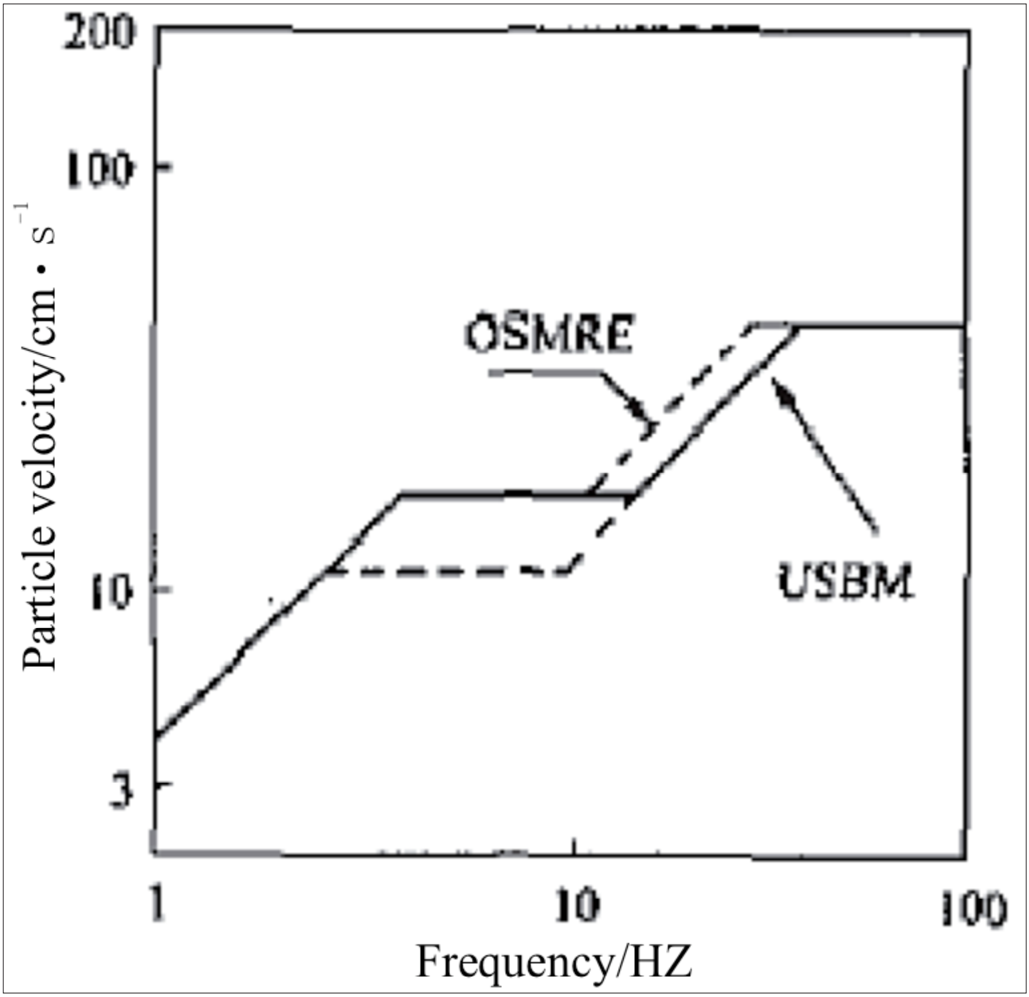

Figure 1. Safety standards of USBM and OSMRE.

resulted in higher vibration levels at distances 1-2 km but at distances of about 500 m housing tenants experienced lower levels. Vibration frequency decreases with distance and at certain distances the frequency was close to the natural frequency of the structures which resulted in rattling due to resonance.

For this reason, currently some developed countries have based their guidance levels on particle velocity and frequency. For example U.S. Bureau of Mines (USBM) and Office of Surface Mining Reclamation and Enforcement (OSMRE) (Figure 1), the German standard (DIN4150-3) (Table 2, Figure 3), the former East German Standards (DDR.KDT) (Table 1), Switzerland (Table 3), United Kingdom blasting vibration safety standards (BS 7385), the British Association of Noise Consultants (ANC) proposed blasting vibration damage criterion, the Irish national road Department (NRA) (Table 4), India Office Mine Safety (DGMS) (Table 5. China's ‘Blasting Safety Regulations’ (GB 6722-2003) (Table 6) is divided into several frequency range sections for allowable vibration velocity.

In general, national standards are prescribing different levels for different types of construction (structures).

Specifically as follows:

(1) United States Bureau of Mines (USBM) and Office of Surface Mining Reclamation and Enforcement (OSMRE) developed recommendations for blasting vibration safety criterion.

In the development of the first blasting

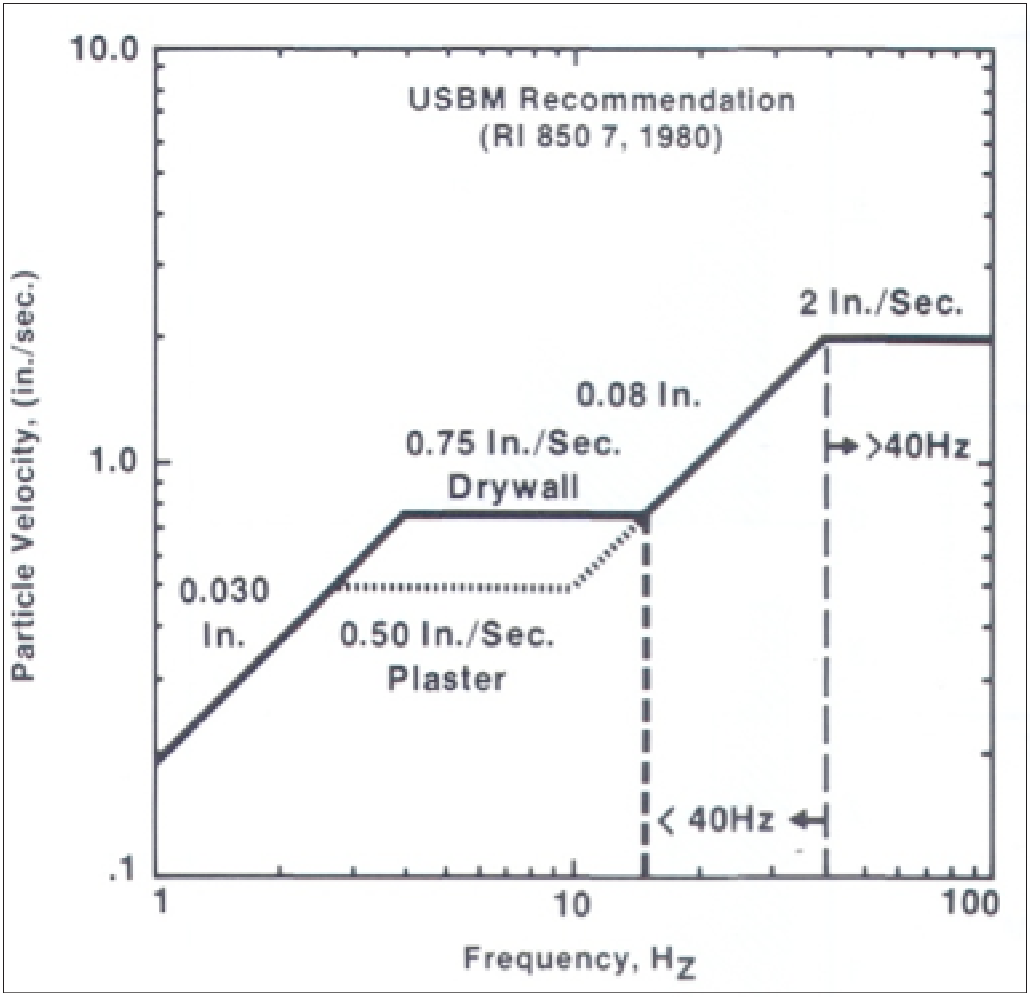

Figure 2. Safe levels of blasting vibrations for houses, USBM.

vibration safety criterion United States has used the peak acceleration as recommended levels with limits of 0.1 -1.0 g for constructions (structures). Duvall and Fogelson (1962) performed statistical analysis of measured data and concluded that particle vibration velocity and damage are closely related and made use of peak particle velocity as a safety assessment standard for the first time. In the subsequent development of blasting vibration safety criterion the vibration frequency of blasting vibration on the destruction of construction (structure) was taken into account. Representatives of the United States Bureau of Mines (USBM) and Office of Surface Mining Reclamation and Enforcement (OSMRE) set up a joint assessment standard as shown in Figure 1. In accordance with the frequency as the abscissa and the peak velocity for the ordinate, each peak plotted in Figure 1. If all points are under the line which is illustrated this will meet the safety standards for blasting vibration.

(2) USBM Report (RI8507) Appendix B - alternative safety standards for blasting vibration.

The standards from U.S. Bureau of Mines (Siskind *et al.* 1980) introduced particle velocity and frequency in their criteria. See Figure 2.

(3) The former East German Standard (DDR. KDT).

The former East Germany standard is divided into four categories, the main considerations are 2 - 30 Hz and 30 - 100 Hz frequency band of peak

Table 1. The former East German Standards (DDR, KDT).

Building category	Frequency range Hz	Vertical peak particle velocity, mm/s
Buildings of historical	2 - 30	2
structure	30 - 100	2 - 14
mucha structure	2 - 30	5
	30 - 100	5 - 36
masonry or concrete structures	2 - 30	10
	30 - 100	10 - 71
Steel, reinforced concrete	2 - 30	30
structure	30 - 100	30 - 215

Table 2. German Standard, DIN4150-3.

Line	Type of structure	Guideline values for velocity, v_i, in mm/s			
		Vibration at the foundation at a frequency of			Vibration at horizontal plane of highest floor
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz *)	at all frequencies
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	3	3 to 8	8 to 10	8

*) At frequencies above 100 Hz, the values given in this column may be used as minimum values.

vertical vibration velocity as shown in Table 1.

(4) Blasting vibration safety Standards, Germany (DIN4150-3).

Compared to the former East Germany safety standard the German blasting vibration safety standard for buildings is divided into three categories with a more detailed division of the frequency band, but also using peak particle velocity as a safety criterion as shown in Table 2 and in Figure 3.

(5) Safety criterion for blasting vibration, Switzerland.

The development of the Swiss blast vibration safety criterion is similar to the former East Germany standard. The construction (structure) is divided into four categories, but also corresponds to two frequency bands. However, the division of frequency bands are very different. Switzerland blast vibration safety criterion mainly considered the peak particle velocity of 10 - 60 Hz and 60 - 90 Hz frequency bands as shown in Table 3.

(6) Irish National Road Sector (NRA) proposed blasting vibration safety criterion.

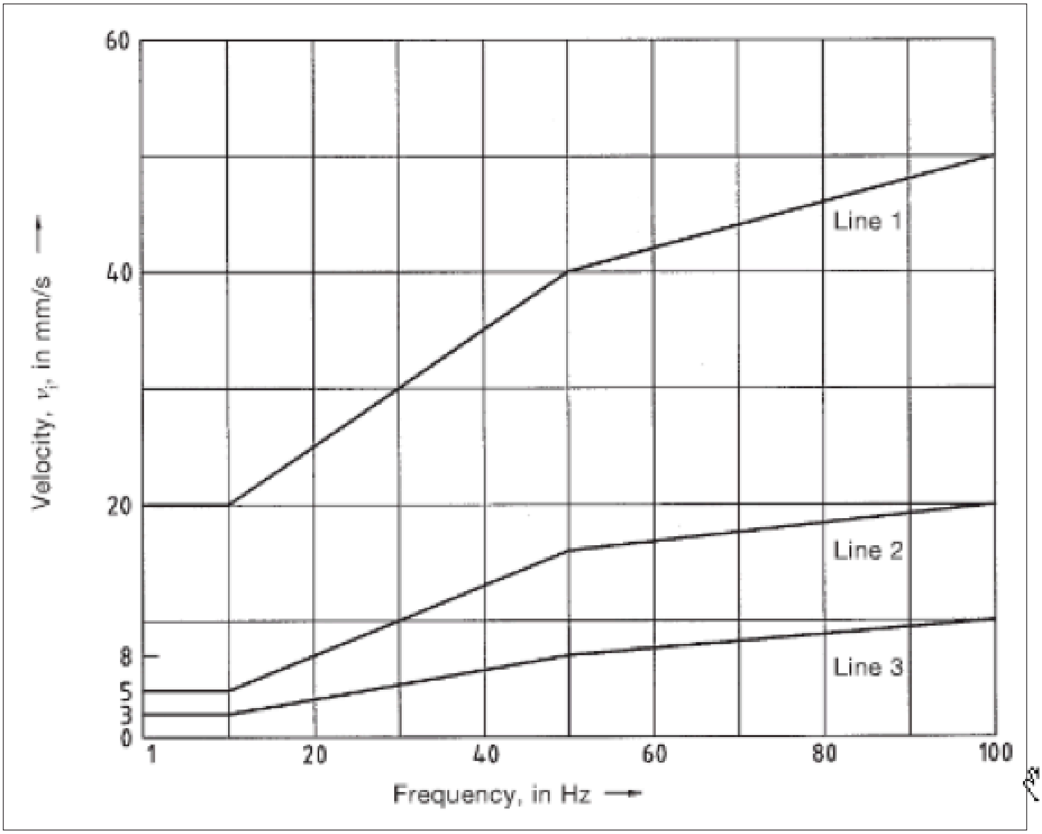

Figure 3. Blasting vibration safety standard DIN4150-3. Line 1-3; See Table 2.

Table 3. Switzerland - Blast vibration standard.

Building category	Frequency range,	HZPeak particle velocity, mm·s-1
Steel, reinforced concrete	10 - 60	30
structure	60 - 90	30 - 40
brick and concrete structure	10 - 60	18
	60 - 90	18 - 25
masonry wall, wooden pavilion	10 - 60	12
	60 - 90	12 - 18
historic and sensitive buildings	10 - 60	8
	60 - 90	8 - 12

Table 4. Allowable vibration velocity, highway construction

frequency range / HZ	< 10	10 - 50	> 50
particle velocity / (cm·s-1)	0.8	1.25	2.00

Table 5. India DGMS safety standards

	main vibration frequency		
for blasting vibrations, (mm/s)building type	< 8 HZ	8 - 25 HZ	> 25 HZ
non-proprietary architecture			
(1) residential building	5	10	15
(2) industrial buildings	10	20	25
(3) sensitive historic buildings	2	5	10
private non-permanent buildings			
(1) residential building	10	15	25
(2) industrial buildings	15	25	50

(7) India Office Of Mine Safety (DGMS) proposed blasting vibration damage criterion.

(8) Blasting vibration safety Standards of 'Blasting Safety Regulations' (GB 6722 - 2003), China.

The original blasting safety criterion vibration had some deficiencies as it did not consider frequency. Blasting workers, with reference to the foreign blasting vibration safety standards, made a revision of the original criterion and published China's 2003 revised 'Blasting Vibration Safety Regulations', (GB 6722-2003). The result can be seen in Table 6. Peak particle velocity and vibration frequency are used as the main joint criterion of construction (structure). And the new standard requires that when a safety level is decided the following should be considered; the importance of the construction (structure) , the quality of building (structures), its resonance frequency, ground conditions and other factors.

3.2 Safety levels based on particle velocity and acceleration

The blasting vibration safety standard of PRC 'Blasting Safety Regulations' GB 6722-2003 is used as a blasting vibration criterion for structures. For houses and monuments the peak particle velocity and the main vibration frequency are important for finding the 'safe allowed velocity'. For structures like hydraulic tunnels, traffic tunnels, mine workings, power plants and newly grouted concrete structures only the peak particle velocity is needed.

In blasting and earthquake engineering the most common parameters used are the maximum accelleration and the peak particle velocity. There are mixed views of which parameter is the best to use. Some believe that particle velocity plays an important role in the damage of building structures.

Our proposal is: The particle velocity as a measure and describe the intensity of blast vibrations.

3.3 Safety levels based on particle velocity; single-component and three-component vector sum

The experimental results obtained in different geological formations show that sometimes the peak vertical component is the largest one and sometimes the peak horizontal radial component or the peak horizontal tangential component is the largest one.

From the structural response of protected construction (structure) perspective, the horizontal vibration tends to control the horizontal response of the construction´s (structure) vertical wall and upper structure. The vertical vibration tends to control vertical response of horizontal plate structure. Particle vibration peak velocity should be three orthogonal components peak vector sum (actual max), rather than the peak of three components (mostly not in the same time) vector sum (nominal maximum). Experimental results show that the latter often is larger than the former by 30 -40%,

Table 6. Blasting Safety Regulations (GB 6722 - 2003), China.

No.	Category of protected objects	Safe allowed velocity / (cm/s)		
		< 10 HZ	10 - 50 HZ	50 - 100 HZ
1	a: soil cave, housing, housing rubble	0.5 - 1.0	0.7 - 1.2	1.1- 1.5
2	a: general brick, non-seismic large block building	2.0 - 2.5	2.3 - 2.8	2.7 - 3.0
3	a: reinforced concrete structure house	3.0 - 4.0	3.5 - 4.5	4.2 - 5.0
4	b: common ancient buildings and monuments	0.1 - 0.3	0.2 - 0.4	0.3 - 0.5
5	c: hydraulic tunnel	7 - 15		
6	c: traffic tunnel	10 - 20		
7	c: mine workings	15 - 30		
8	hydropower and Power Centre control room equipment	0.5		
9	d: large volume of fresh concrete			
	age : Initial setting - 3 d	2.0 - 3.0		
	age : 3d - 7d	3.0 - 7.0		
	age : 7d - 28d	7.0 - 12		

Note 1 : The max peak particle velocity shall be within the frequency span mentioned.in the table.
Note 2 : Frequency range should preferably be measured. The frquency range can be estimated by a rule of thumb for predominant frequencies: Chamber blasting < 20 HZ, deep-hole blasting 10 - 60 HZ, Shallow hole blasting 40 - 100 HZ.

a : when a safety level for a building is selected one must take the following into consideration; the importance of the building, the construction quality, its resonance frequency, ground conditions and other factors.
b : safety levels of ancient buildings should be selected by the expert panel discussion and reported to the appropriate cultural relics management department for approval.
c : when selecting safety levels for tunnels and roadways the following should be taken into account; the importance of structures, rock conditions, section size, depth, the explosion source direction, the vibration frequencies and other factors..
d : when selecting the safety level for new castings of non-massive concrete choose the upper limits given in the table..

but generally three orthogonal components peak vector sum is often larger by 10-20% than the peak of each single component.

Therefore, sometimes starting from the convenience of the implementation; Testing only the vertical component of particle vibration velocity or the vertical component and a horizontal component, measuring the maximum of the peak component to assess the safety of blasting vibration effect is unreasonable and inappropriate.

A smaller safety factor may cause an engineering accident or even catastrophic consequences. If the safety factor is too large this will inevitably lead to project cost increases.

4. CONCLUSIONS AND RECOMMENDATIONS

(1) Velocity - frequency two-factor safety blasting vibration criterion has become a consensus in developed countries. It is also used in China's National Bureau of Standards (2003) Blasting Safety regulations (GB 6722-2003).

(2) Throughout the many nations' blasting vibration safety standards, researchers generally use particle velocity as the main standard but rarely acceleration (in some special industries, such as China's nuclear power industry acceleration is used as a Standard). Combined with these reasons listed

in this paper, the use of particle velocity as the standard of blast vibration intensity is more scientific and reasonable than the use of displacement and/or acceleration and it is proposed to consider using particle vibration velocity.

(3) For the selection of single-component particle vibration velocity and three-component vector sum, different countries have different options.

According to the reasons described in the article, the use of three orthogonal components peak particle velocity vector sum (actual max) is most consistent with reality, so it is proposed to use the peak vector sum. Of course, in practice, if only to compare vibration attenuation at various measuring points, just measuring the largest component is also feasible.

REFERENCES

Bollinger, G.A. 1971. Blast Vibration Analysis, *Southern Illinois Press*, Carbondale, Illinois, USA.

DIN 4150-3. 1999. Structural vibration - Effects of vibration on structures, *Deutsche Norm*.

Duvall, W.I. and Fogelson, D.E. 1962. Review of criteria for estimating damage to residences from blasting vibrations, US Bureau of Mines, Report of Investigations 15968.

National Bureau of Standards. 2003. Blasting Safety Regulations (GB 6722-2003) , Beijing: China Standards Press,(In Chinese).

Nicholls, H.R., Johnson, C.F. and Duvall, W.I. 1971. Blasting Vibrations and Their Effects on Structures, US Bureau of Mines, Bulletin 656.

Rockwell, E.H. 1927. Vibrations caused by Quarry Blasting and Their Effect on Structures, *Rock Products, Vol 30*, pp 51-61.

Siskind, D.E., Stagg, M.S., Kopp J.W. and Dowding, C.H. 1980. Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, *US Bureau of Mines, Report of Investigations* 8507.

Swedish Standard SS4604866. 1991. Vibration and Shock-Guidance Levels for Blasting-Induced Vibration in Buildings, *SIS, Box 3295, 10366*, Stockholm, Sweden.

Zhang Xueliang and Huang Shutang. 1981. Blasting seismic effect, Beijing: *Earthquake Press*, (in Chinese).

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

GPG for the safe storage of Solid Technical Grade Ammonium Nitrate

E. C. Nygaard
Yara International ASA, Porsgrunn, Norway

ABSTRACT: This Good Practice Guide (GPG) for storage of Solid Technical Grade Ammonium Nitrate was developed by global manufacturers of ammonium nitrate to provide guidelines for the storage of Technical Grade Ammonium Nitrate (TGAN) at manufacturing, distributors' and end-user sites. The ultimate goal is to promote safety and health of personnel, to prevent damage to property and to avoid hazards to the environment. The GPG contains information on design, location, construction and operation of stores for TGAN. In addition it outlines the recommended content of a Safety Management System (SMS) catering to the health and safety of the community, employees, property and the environment. Such a SMS should be in place at all TGAN storage facilities covered by the GPG. In the location of a TGAN store factors to be considered take into account the likelihood and related consequences of an incident associated with TGAN at the storage facility. To facilitate such an evaluation the GPG contains a risk assessment flowchart as well as several examples.

1. INTRODUCTION

Ammonium nitrate (AN) is a product manufactured and used in increasingly significant quantities, both in the agricultural industry as fertilizer and in the mining industry as an explosives precursor. Due to its chemical properties, ammonium nitrate is classified as a Dangerous Goods under the United Nations Recommendations on the Transport of Dangerous Goods – Model Regulations 16th Edition and the International Maritime Dangerous Goods Code.

TGAN (within specification) does not burn, but if exposed to elevated temperatures, for example in a fire, it will decompose emitting toxic gases. In some situations, for example under confinement and intense fire and/or with contamination a decomposing mass of TGAN can explode, and even undergo transition to detonation. Another hazard associated with this material is a detonation initiated by an intentional act, a fire, chemical contamination and/or a high velocity projectile. The probability of a detonation of pure TGAN occurring without one of these four scenarios is extremely low.

This document has been developed to provide guidance to organizations that store TGAN to further minimize the unlikely potential for an incident by applying prudent risk management principles and practices.

The information contained herein is to be used as a guide only. However, adherence to this code will reduce the possible consequences of an unplanned event. The values used for separation distances and TNT equivalences are based on currently available information and are subject to change. Any such changes may be incorporated into subsequent revisions.

The ultimate goal of this document is to promote safety and health of personnel, to prevent damage to property and to avoid hazards to the environment.

2. SCOPE

The Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate, has been prepared by an international industry working group on Ammonium Nitrate. It was published in September 2010 in the SAFEX Good Explosive Practice Series GPG 02. It sets out the guidelines for the storage of Technical Grade Ammonium Nitrate at manufacturing, distributor, storage and end-user sites.

TGAN is covered mainly by UN Numbers UN1942 and also by UN2067; in some countries e.g. US and Canada, it is classified as Class 5.1 Dangerous Goods under the United Nations Recommendations on the Transport of Dangerous Goods – Model Regulations, 15th Edition. Classification is subject to individual national regulation but generally is in accordance with the United Nations Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria, Fourth (Revised) Edition.

The GPG also addresses the storage of out-of-specification AN (which is outside UN1942) generated as a result of:

- Off-spec product from process
- Spillages during either transport or handling (at manufacturing plants, storage and end-users sites)
- Product which has been exposed to possible contamination with unknown material (for example: product returned from a customer in bags which are either unsealed or not original).

This document does not cover:

- Fertiliser grade ammonium nitrate (UN2067)
- Ammonium nitrate grades fall under UN 1942 and with a density greater than 0.90 g/cc
- Ammonium nitrate mixtures, which are Class 1 Dangerous Goods (UN0082, UN0222, UN0331)
- Packaging and transport requirements
- Ammonium nitrate solutions or emulsions, suspensions or gels (UN3375)

3. OVERVIEW OF CONTENT OF GPG

- Definitions
- Safety and Management System
- Regulatory Requirements
- Site Design, Construction & Management
- Location of Storage Facilities
- Operation of Stores
- Security Requirements
- Appendices
    - Storage facility location
    - Risk assessment process
    - Security plans
    - Properties of Ammonium Nitrate
    - Hazards of Ammonium Nitrate

4. SAFETY MANAGEMENT SYSTEMS

A Safety Management System (SMS) catering to the health and safety of the community, employees, property and the environment should be in place at all TGAN storage facilities covered by this document. It should be compliant with local regulations and company policy.

The SMS should apply to all employees at the facilities as well as visitors and contractors involved. The SMS should be documented and contain the following key aspects, which should be considered depending upon the site complexity:

- Safety Policy
- Plan Framework
- Training
- Procedures
- Emergency Response

5. REGULATORY REQUIREMENTS

Operators of TGAN stores must comply with legislation applicable to the storage and handling of TGAN.

6. SITE DESIGN, CONSTRUCTION & MANAGEMENT

The following types of stores are commonly used to contain TGAN:

- Open air compounds – IBCs, packages
- Freight containers – IBCs, packages, bulk
- Silos/Bins – Bulk TGAN
- Buildings – IBCs, packages, bulk

Construction should be consistent with the local and national or Federal requirements.

6.1 General requirements

The general requirements focus on:

- Electric
- Construction
- Signage
- Security
- Emergency

6.2 Specific recommendations for various types of storages

The following types of stores are commonly used to contain TGAN:

- Open Air Compounds
- Freight Containers for Storage
- Silos or Bins
- Buildings

6.3 Storage of large amounts of TGAN at mine site

There are situations where, in remote locations, a large quantity of AN must be shipped in and stored. The storage of large quantities of AN is not without attendant hazards and risks, especially, at remote locations such as mine sites or isolated communities where emergency response or evacuation may be complicated by the location and elements.

In situations at mine sites where large amounts of TGAN are stored (even as transit storage), it is recommended that:

- The size and layout of individual storage stacks/piles are determined by the risk assessment.
- Community or mine site emergency response and evacuation procedures be reviewed to ensure that they adequately cover fire and / or explosive events at a bulk TGAN storage facility.
- The design of the TGAN storage & handling facilities and equipment include all reasonable means to prevent and control fire, and that local authorities review and approve the design and construction of the building and its equipment, e.g., following of US NFPA guidelines for the storage of large quantities of AN.
- Appropriate local standards for transportation of AN be met.

6.4 Fire-fighting considerations

TGAN is an oxidizing agent. It does not burn but is a strong supporter of combustion. The presence of some contaminants may increase the probability of a fire. In a fire, TGAN will decompose and produce toxic combustion products such as oxides of nitrogen, ammonia and nitric acid fumes. The properties of TGAN, its mass and location of the store influence detailed fire-fighting requirements. They should be determined by a fire risk assessment carried out by competent personnel. The fire fighting requirements can be reduced for isolated stores where a potential explosion or fume emission will not impact on people or property on or away from the premises. It is important to remember the impact of firewater effluent on the environment through the construction of effective drainage systems.

6.5 Contaminated TGAN storage

After the Toulouse accident, a new category for AN materials was created by the European Parliament. Therefore the Council Directive 96/82/EC was amended to create the “Off-spec” category for AN. Off-spec AN is more common in AN manufacturing plant and large storage sites rather than end-user sites. This code has addressed ‘contaminated’ TGAN as a special category.

Key requirements:

- The maximum amount of contaminated material to be stored should not be higher than 50 tonnes per independent stack/pile.
- The holder of the material must conduct a risk assessment on each batch of off-spec AN to ensure that the detonation risk is minimized.
- Each contaminated material must be segregated.
- Contaminated material must be handled as

explosive whether or not the material has been contaminated with organic material.

− Contaminated materials disposal must be done through methods such as dissolving it in water or blending. The selection of one method or another will depend on a proper risk assessment.

7. LOCATION OF STORAGE FACILITIES

7.1 *General*

The siting and layout of TGAN storage is based on minimizing the risk from an event within the storage facility. Factors considered in the location of a TGAN store take into account the likelihood and the related possible consequences of an incident. Owners and operators of TGAN storage facilities are encouraged to continually manage safety and security aspects of operations through control measures that reduce the likelihood of any incident.

The possibility of detonation of a significant mass of TGAN is the dominant issue for the siting and layout of TGAN storage facilities. While toxic combustion products may be a key consideration in designing fire detection, suppression and emergency response measures, they are not specifically addressed in this section.

Owners and operators of TGAN stores should adhere to the Quantified Risk Assessment (QRA) method mandated by their relevant regulatory authority(ies). Where this mandate is absent, other QRA processes accepted by the industry, for example IMESAFR, should be employed.

7.2 *Risk-Based Approach for siting and layout*

The general approach for risk-based assessment is presented in Figure 1. For a large manufacturing site, a QRA shall be conducted which includes an assessment of the risk controls. If storage is less than 2,500 tonnes a simplified assessment may be undertaken in lieu of a full QRA. For sites with mixed storage (TGAN and explosives), the Explosives Regulations that pertain will determine the siting and layout. More details on locating TGAN storage facilities, and a sample Risk Assessment methodology are found in Appendices A and B of the GPG.

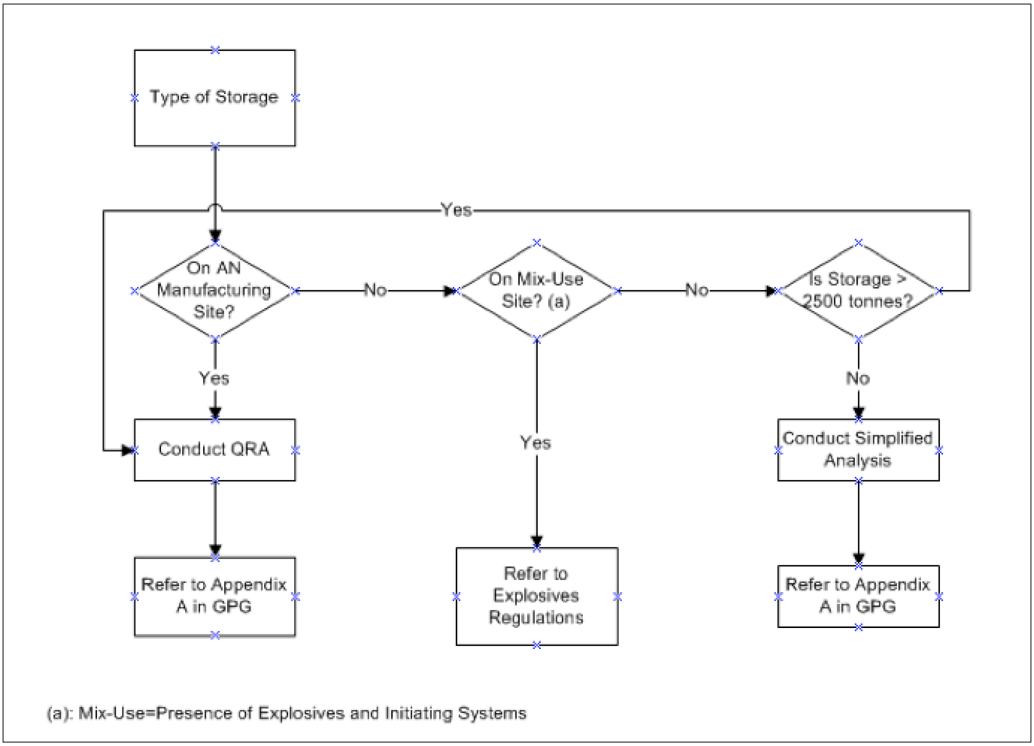

Figure 1. Overall Risk-Based Approach.

8. OPERATION OF STORES

The operating procedures and layout of stores are designed to ensure safe operation (e.g. adequate access, stack stability) and to minimize the contact of TGAN with combustible materials (e.g. vehicle fuel, pallets). These control measures are aimed at reducing the likelihood of an incident.

Other factors may include the separation of stacks and piles. The size of an individual stack or pile is a key factor in determining the required separation distances between stacks and piles.

The GPG contains an extensive list of general as well as special recommendations for the operation of different types of stores.

9. SECURITY REQUIREMENTS

Security plans may be required by the regulatory authority and good business practices. However, even if this is not a requirement, developing such a security plan based on the vulnerability (control of contaminated product) of the storage facility and the threat in the area of operation must be a serious consideration. Where appropriate, provision of additional levels of security may reduce the likelihood of a given event. Guidelines for addressing security issues are given in Appendix C of the GPG.

10. STORAGE FACILITIES LOCATION

In the location of a TGAN store, factors to be considered take into account the likelihood and related consequences of an incident associated with TGAN at the storage facility.

Owners and operators of TGAN storage facilities are encouraged to continually manage safety and security aspects of operations through control measures aimed at reducing the likelihood of any incident. By the use of best management and handling practices by manufacturers, TGAN has been and can continue to be stored safely without incident. The following steps provide the logic for siting such a storage facility:

- Determine the type of TGAN Storage such as whether it is on a TGAN manufacturing plant or a site on which explosives are manufactured / stored (i.e. mixed use) or an independent storage facility.
- If the site is mixed-use then the Explosives Regulations must be consulted and the TGAN facility sited accordingly, using a Q-D approach, followed by a risk-based approach as appropriate.
- Determine whether a full QRA is required. For example, if the mass being stored is small a full QRA may be considered excessive and a simplified risk analysis can be conducted.
- If the site is on a TGAN manufacturing plant, or if the mass of TGAN stored is above 2,500 tonnes:
  - Determine mass of TGAN (M)
  - Determine TNT equivalence (NEQ)
  - Determine the risk by carrying out a QRA. The process involves estimating both the likelihood of the event occurring and the consequences if it does occur.
  - If the level of risk identified through the QRA is acceptable, no further analysis is required.
  - If the level of risk is not acceptable, it should be lowered through a combination of additional control measures that will reduce the likelihood, and/or reduce the donor/acceptor quantity (i.e. the consequence).
- If there is no need to carry out a QRA (e.g. the storage quantities are small and/or the siting layout is simple), the layout can be set by carrying out a simplified risk or consequence analysis. The mitigation methods are the same as above –i.e. reduce the mass or separate the piles of TGAN (manage the consequence) or implement additional controls (reduce the likelihood) and hence the overall level of risk.

This logic is shown schematically in Figure 2:

The dominant issue for the siting and layout of TGAN storage facilities is the possibility of an explosion of a significant mass of TGAN. While toxic combustion products may play a key role in design aspects such as fire detection, suppression and emergency response, they are not specifically addressed in this section.

- Mitigation of the risk of a mass explosion of TGAN requires reducing the:
- Likelihood of an incident by implementing control measures and procedures
- Possible consequences through:
  - minimizing the mass of TGAN in a given

storage unit (bulk pile, bin, or bag stack); and/or
- increasing the separation distance between TGAN storage units.

10.1 Separation of TGAN stacks, piles and silos

A storage facility may contain one or more bag stacks, bulk piles or silos of TGAN. The following paragraphs set out the separation requirements for these situations. These separation requirements are intended to prevent a detonation in a stack or pile initiating adjacent stacks or piles.

If these separation requirements are met, the quantity of TGAN considered as a potential explosive source is the quantity in each individual stack or pile. If the separation requirements are not met, the quantity of TGAN in the individual stacks or piles must be summed to give the size of the potential explosive source. This has important consequences in a risk assessment process.

10.1.1 Bags and IBCs

The recommended separation distances listed below are based on simulations. Further large scale testing may change these recommendations.

The gap separation distances between each stack shall be maintained as follows (Nygaard 2008) for the various densities of TGAN:

− Low density (less than 750 kg/m3 or 0.75 g/cc), high porosity TGAN stacks that are 'normally' configured (i.e. set back by ½ bag at each layer) should be separated by 16 meters (Yara International Publications). For a 'pyramidal' stack, the separation can be reduced to 9 meters.

− Medium density (between 0.75 and 0.85 g/cc) TGAN stacks should be separated by 9 meters for a normal configuration and reduced to 7 meters for a pyramidal configuration.

− High density (greater than 0.85 and less than 0.90 g/cc) TGAN should have a separation gap between stacks of 1 meter (The basis of which is still to be confirmed by field tests).

It has been shown (Nygaard 2008) by simulations that configuration (geometric layout) of the stack affects separation distance (still to be confirmed by field tests). This may need to be considered when determining appropriate separation distances for the stacks.

The separation distances between stacks may be reduced if a barrier capable of inhibiting initiation of the neighbouring stack is installed.

10.1.2 Bulk Storage

Large quantities of solid TGAN have been stored successfully in bulk stores around the world for extended periods and without harmful consequences. The very limited number of incidents that have occurred can be traced to poor handling or management practices.

The objective of this document is to identify those good practices for managing the bulk storage of TGAN that will minimize/eliminate the likelihood of a harmful event.

10.1.2.1 Major Manufacturing Sites

When designing a facility for storage of TGAN on major manufacturing sites, the amount of storage incorporated into the design should be minimized without compromising the facility's viability and operational efficiency. Off-specification material as manufactured, should be handled as required by any local regulations e.g. Seveso. The cyclical nature of the given markets and the quality control of the final product should also be considered. Typically, bulk storage of 3,000 to 6,000 tonnes of TGAN is sufficient to enable the efficient operation of a large (~350,000 tonnes per annum) TGAN manufacturing site. The proposed location and quantity of the storage facility for TGAN must be incorporated in the QRA for the manufacturing site.

Globally there are a significant number of TGAN bulk storage facilities on manufacturing sites that have an existing capacity in excess of 10,000 tonnes. These manufacturing sites are unique in that they are attended by highly skilled operations personnel for 24 hours a day, seven days a week. They also have well-developed Safety Management Systems, normally incorporating Process and Engineering Safety management to comply with local regulatory requirements (e.g. PSM in the US; COMAH in UK; MHF in Australia).

Existing manufacturing sites should review the QRA for the site taking into account the most recent technical information regarding the storage of TGAN. Where the site does not have a QRA, then one shall be undertaken to ensure sufficient controls are in place to reduce the risk of a harmful incident to As Low As Reasonably practicable (or ALARP) requirements.

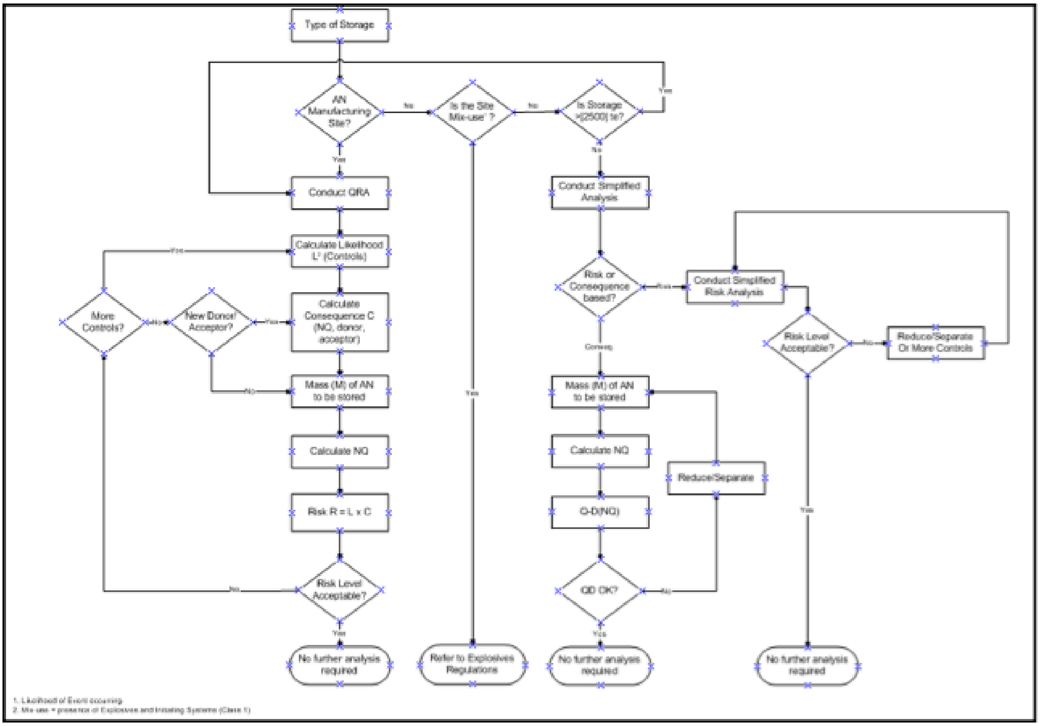

Figure 2. Flowchart depicting the logic for a simplified Risk Analysis.

From 'The Tolerability of Risk from Nuclear Power Stations', (HSE, 1988). In weighing the costs of extra safety measures the principle of reasonable practicability (ALARP) applies in such a way that the higher or more unacceptable a risk is, the more, proportionately, employers are expected to spend to reduce it. Legally speaking, this means that unless the expense undertaken is in gross disproportion to the risk, the employer must undertake that expense.

10.1.2.2 Mixed Sites

Where it is proposed to store TGAN on sites where other potentially explosive materials (e.g. boosters, detonators and other Class 1 Explosives) are or will be stored, additional criteria apply. The siting of the TGAN storage facilities with respect to other storage areas and external communities shall be in accordance with the relevant local explosives regulations.

10.1.2.3 Sites with less than 2,500 Tonnes Storage Capacity

2,500 tonnes of TGAN storage is the threshold value at which specific regulatory requirements come into force in various jurisdictions (e.g. Major Hazard Facilities regulations in Australia and the European Seveso II directive).

If the proposed or existing quantity of TGAN to be stored is less than 2,500 tonnes, a simplified risk analysis should be conducted. This will indicate if the separation distance should be determined by either a consequence or a risk based analysis.

For example, if the proposed storage is in an isolated area and well away from residential and other local community establishments, then a simple Q-D calculation could be used to determine the appropriate separation distance. Should the Q-D calculation indicate there is a risk that local communities could be impacted by an event, then a simplified risk assessment SRA should be conducted to determine the control measures required to minimise the likelihood of a harmful event on the surrounding communities.

10.2 Estimation of Net Explosives Quantity (NEQ)

The first step to minimise the consequence of any TGAN event focuses on the mass involved - whether as loose prills in a bulk pile or prills contained in a of explosive substance (NEQ) in the TGAN mass under consideration must be determined. The NEQ is calculated by estimating the overall TNT Equivalence of TGAN and multiplying that by the total mass of TGAN.

NEQ (Q) = Overall TNT Equivalence (Eo) x Mass of TGAN, (M)

The TNT equivalence provides an estimate of the blast energy of TGAN relative to TNT. To determine the Overall TNT Equivalence (Eo) of TGAN it is necessary to combine Chemical TNT Equivalence with the Explosive Yield. The relationship is:

Overall TNT Equiv (Eo) = Chemical TNT Equiv. (Ec) x Explosive Yield (Ey)

The Chemical TNT Equivalence is a ratio based on the relative Heat of Combustion of the material compared to TNT. For the purposes of this calculation, the chemical equivalence for each TGAN event scenario is estimated as 32%. (Note: this value is used for illustrative purposes only. There is an active program underway to determine this value for AN storage piles. New information will be included in the next revision of this document.) The Yield or Efficiency (Ey) is an estimate of the TGAN mass that is consumed in the detonation.

10.3 Estimation of Separation Distance using the Q-D Tables

Once the NEQ (Q) has been estimated, the distance (D) of the storage site to nearby facilities can be obtained from the Explosives Q-D Tables.

If the required distance D is too large for a given storage mass M, the process can be repeated with a smaller mass, if such a mass is practicable. If it is not practicable to reduce the quantity of TGAN stored further, then a risk assessment approach may be required

10.4 Estimation of Risk

Risk is the product of the consequences of an event and the likelihood (frequency) of the occurrence of the event. Hence, risk can be reduced by control measures, where practicable, that decrease the potential consequences and/or likelihood of the occurrence. The four likely scenarios for an explosion involving a TGAN manufacturing or storage site are:

- Fire
- Contamination
- Shock impact with high velocity projectile
- Malicious act

10.4.1 Likelihood

A variety of measures can be used to reduce the likelihood of each of these scenarios are listed in the GPG. The estimated likelihood of an explosion can be site specific and may require detailed study for industrial and mixed storage sites.

10.4.2 Consequence

The major consequence of an explosion is related to the overpressures generated by the explosion. The overpressure at a particular location is determined by the explosive energy from the TGAN involved in an explosion and the location of the persons or property at risk from the explosion i.e. the distance. For off-site people and property, sufficient separation distances from the potential explosion sources can reduce the risks to acceptable levels.

If this control measure is not adequate, changes in the quantity and layout of the TGAN storage may be sufficient as an additional control. However, further controls may be required if it is not practicable to reduce the overall risk sufficiently using the above measures.

If necessary, a full QRA should be carried out to determine the level of risk for a given TGAN storage site. The Organization and Competent Authority can then decide whether this level of risk is acceptable or not. The competent authority will review any QRA by a close examination of assumptions and risk examination. The process of carrying out a QRA is not within the scope of the GPG.

11. CONCLUSIONS

This ‘Good Practice Guide for the Safe Storage of Solid Technical Grade ammonium Nitrate’ is an initiative by Global AN manufacturers to adopt a single approach, which will be independent of geography. It contains information on design, location, construction and operation of stores for TGAN. In the location of a TGAN store factors to be considered take into account the likelihood and related consequences of an incident associated with TGAN at the storage facility. The intention is that the GPG shall be a ‘live’ document and will be revised when updated background information is available (e.g. TNT equivalence, stack configuration).

12. ACKNOWLEDGMENTS

Thanks to:

- The participants of the International Industry Working Group on Ammonium Nitrate
- SAFEX for issuing the guidelines under their “umbrella” and allowing me to present it at the EFEE Conference.

REFERENCES

Nygaard, E. 2008. Storage of Technical (Porous) Ammonium Nitrate. *Proceedings of ISEE Conference.*

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Environmental impact of blasting in quarries and public works

J. Dernoncourt & J. Couvrat
Drilling and Mining, Alpharoc Ouest – EPC Group

F. Martareche
BEC Frères – Fayat Group

ABSTRACT: Synduex has commissioned research into the environmental impact of industrial explosives in quarries and on public works sites. Drawing on discussion at the Grenelle de l'environnement (a national Environment Round Table set up by the French government), this analysis gives an idea of the energy efficiency of drilling and mining by means of an eco-comparison tool (Ecofro) for the different fragmentation methods used by the profession.

1. INTRODUCTION

A common definition of drilling/mining is the combination of a drilling machine, explosives and … damage! Suffering from this image, mining has sometimes been seen as a last resort for fragmentation, when the rock makes a hydraulic rock crusher, ripper, planing machine and other mechanical equipment ineffective. However, the profession has made significant progress in recent decades. The art of mining now follows rigorous techniques, particularly thanks to new explosives (bulk emulsions from a mobile explosive manufacturing unit), new methods of priming (electronic detonators) and new measuring equipment (laser readings of the rock face, deviation measurement probes, GPS site positioning). These techniques enable potential damage caused by the use of explosives to be managed and help make drilling/mining the most popular method as early as at initial design stages of a public works programme.

But is this technical expertise enough to make drilling/mining the leading method of rock fragmentation? Surprisingly, new environmental constraints may meant that drilling/mining is ahead of the game.

2. SYNDUEX'S ENVIRONMENTAL POLICY

Faced with new environmental problems such as global warming, eutrophication and soil pollution, Synduex began in 2008 to analyse the environmental impact of industrial explosives in quarries and on public works sites. Aware of the advantages of this powerful, effective and cost-efficent fragmentation method, the specialist union wanted to asses the known chemical pollution from explosives and define their carbon footprint and energy efficiency.

This policy took shape through a research project by a student engineer at the Ecole des Mines in Alès, called 'The environmental impact of industrial explosives in quarries and on public works sites – carbon and energy footprints'. Helped by the presentation of this work at the European explosives conference organised by the EFEE in Budapest in 2009, Synduex decided in 2010 to continue its work on greenhouse gases and energy efficiency in drilling/mining by producing a practical eco-comparison tool for rock fragmentation methods: ECOFRO.

The ultimate objective for Synduex is to create a tool that enables a complete environmental comparison of different rock fragmentation methods in quarries and on public works sites. This tool would tackle the issues of greenhouse gases, dust, noise and vibration.

This article outlines the conclusions of the first study carried out by Synduex as well as the functioning and aims of its new eco-comparison tool ECOFRO. It also describes the opportunities that greater use of explosives in quarries and public works could bring in terms of carbon and energy footprints for the production stages after quarrying.

3. CURRENT AND FUTURE ENVIRONMENTAL CHALLENGES

Greater awareness of the environmental stakes and new regulation to limit and reduce the impact of industry on the environment have created a new criterion for companies choosing techniques and tools: the environmental impact.

The public-works sector has long paid great attention to its environmental impact, the potential harm and damage to the environment. Many sites are therefore currently designated HQE (High Environmental Quality) or even THQE (Very High Environmental Quality) or 'green sites'. The regulation for quarries aims to minimise their impact on the environment and cement plants are particularly affected by the new restrictions in terms of greenhouse gases.

To recap, among the main sources of industrial pollution, the manufacture and use of explosives can have an impact on:

- The greenhouse effect or global warming that originates in the production of gases: CO_2, NO, NO_2, N_2O.
- Eutrophication, which consists of excessive discharge of phosphates or nitrates, primarily in water, and significantly reduces biodiversity.
- Acidification of water through the emission of sulphur dioxide and nitrogen oxides that damage flora and the wider ecosystem.

But these environmental concerns have evolved hugely in recent years, in particular through the implementation of a policy with targets to limit and reduce greenhouse gas emissions through a national greenhouse gas quota plan (PNAC). Without removing responsibilities on pollution, this policy limits greenhouse gas emissions for the most-polluting companies. The number of companies affected will increase with each new quota acquisition plan. Companies which exceed the quotas will face financial penalties or have to buy additional quotas on the CO_2 BlueNext exchange.

In a wider context, the European Union ratified in December 2008 the 'Climate-Energy' pact or the '20-20-20' objectives:

- To reduce greenhouse gas emissions by 20% relative to their 1990 level by 2020.
- To reduce energy consumption by 20% (i.e. increase energy efficiency).
- To increase the share of renewable energy to 20% of consumption.

4. ENVIRONMENTAL IMPACT OF EXPLOSIVES

4.1 Composition of explosives

In order to reflect the French and European market accurately, the explosives studied are cartridge emulsions, ANFO or ammonium nitrate-fuel oils, dynamite and bulk emulsions or ballasted ammonium nitrate fuel oils. The total civil explosive mass used in France is 45 000 tonnes per annum. This quantity fluctuates slightly year on year depending on which large public works sites in France require the use of explosives (large-scale earthworks sites to build motorways, TGV lines etc.). Overall, the mass of explosives used to blast rocks in quarries is stable over time.

This total quantity of civil explosives can be broken down as follows:

- 10% dynamite
- 40% ammonium nitrate-fuel oils
- 30% bulk emulsion (or 'slurry')
- 20% cartridge emulsion

Modern civil explosives are chemical compounds combining an oxidant and a fuel made up of the following basic molecules:

- Carbon: C
- Oxygen: O
- Nitrogen: N
- Hydrogen: H

Aluminium, found in numerous explosives does not actually play a direct role in the chemical reaction that produces the explosion, but acts as a catalyst. Ideally, explosive formulation is therefore based on a comburant-combustible balance, known as the oxygen balance, which must be nil. However, in practice it is preferable to have a slightly negative oxygen balance in order to limit the production of gaseous oxides such as NOx nitrogen oxides.

- Many dynamite compositions are possible. The generally accepted composition for dynamite is a mixture of: nitroglyceroglycol (nitro-glycerine + dinitroglycol), ammonium nitrate, nitric cotton, wood flour, dinitrotoluene or trinitrotoluene, peat, salt and aluminium.
- Ammonium nitrate-fuel oil is composed of technical ammonium nitrate, domestic fuel oil or other fuels such as nitro paraffin, and occasionally aluminium and anti-caking agents. The ideal proportion is 96% ammonium nitrate to 4% mineral oil.
- Cartridge emulsions contain a high proportion of ammonium nitrate, mineral or organic nitrates, mineral oil or wax for fuel, tension-active agents, water and various additives such as aluminium. Bulk emulsions or ballasted ammonium nitrate fuel oils have the same composition but in different proportions.
- Detonators are more powerful compounds (detonation speed of 8000 m/s compared with 6000 m/s for dynamites and cartridge emulsions and a minimum of 3000 m/s for ammonium nitrate fuel-oils) and more sensitive. They are composed of penthrite (PETN), hexogen, octogen and hexolite, glass fibre, carbon.

4.2 Component toxicity

Research into the chemical properties of explosives components has enabled us to define pre-explosion toxicity. This depends on the degree of impact:

- Components with no effect on the environment: water, aluminium, wax;
- Components with an immediate impact but which do not cause any damage to living organisms: nitro-glycerine, low dose ammonium nitrate;
- Components with an irreversible effect on the environment and living organisms: trinitrotoluene, dinitrotoluene.

This last category is no longer a cause for concern in France as these components are no longer used in dynamite manufacture. The impact of pre-detonation explosives is non-existent today in standard explosive usage (see Other forms of pollution).

4.3 Pollution produced by explosive blasting and its effects

Bibliographical research and the study of detonation chemical reactions have enabled definition of the gaseous residues emitted during detonation. These differ in terms of their impact on the environment.

Inert gases whose only potential danger is excessive concentration levels that could result in asphyxia:

- N_2 - nitrogen
- H_2 – hydrogen
- CH_4 – methane
- O_2 – oxygen
- CO_2 – carbon dioxide or carbonic gas
- H_2O – water vapour
- Al_2O_3
- Na_2O.

Short-term harmful gases with no cumulative effect:

- NH_3 (irritation) – ammonia
- CO (toxic) – carbon monoxide
- NO_x (toxic) – nitrogen oxides

Gases that are dangerous when accumulated in the environment: greenhouse gases:

- CO_2
- CO (this gas is also harmful when accumulated in the organism)
- CH_4
- NO_x,

In spite of a lack of scientific research on overall emissions from explosive detonations, it would appear that the gases measured during experiments or predicted by thermochemistry and their concentration do not pose any particular threat to humans or the environment under normal usage conditions: open quarries and sites, with a delay before any subsequent movement in the detonation zone.

4.4 Indirect pollution

By identifying the 'direct' residues of these detonations, other potential 'indirect' residues, which can be formed from gases emitted during explosive blasting, can be identified. These new products are:

- N_2O (powerful greenhouse gas and toxic to humans) – nitrogen protoxide
- NH_4NO_3
- NH_4-CO_3H
- Al_2O_3-Na_2O

Although we do not yet know how to measure the concentration of these components exactly, we can say that they remain at very low levels because they are produced in only limited quantity by 'direct' gases.

The prediction of new complex detonation residues could justify a comprehensive experimental study of the gases resulting from explosions. Based on our knowledge to date, we can nevertheless say that these concentrations remain at levels that are not harmful to man or the environment.

4.5 Other forms of pollution

Potential forms of pollution other than those from detonation have been identified:

- The dissolving of ammonium nitrate or oil in water, which can occur in a mine shaft containing water.
- Management of explosive packaging after detonation.
- Detonator management after blasting.

In addition to its limited environmental impact, the dissolving of products in water can only occur through incorrect use of explosives and only concerns a small quantity of pollutants. The other forms of pollution do not have a serious impact on the environment: explosive packaging is made from plastic and cardboard materials and therefore non-toxic.

5. CARBON AND ENERGY FOOTPRINTS OF DRILLING / MINING

5.1 CO_2 equivalent of explosives

Greenhouse gases emitted during the detonation of explosives have been specifically studied. Based on available theoretical and experimental data, a method for calculating the CO_2 equivalent of using an explosive has been established. For this, the average mass of each gas emitted during detonation had to be defined. Previous studies to measure these gases and software designed to calculate gaseous residues from nitro-chemical Detheocalc98 detonations established a relationship between the theoretical and experimental values, thus enabling the quantities of gas emitted to be estimated. As the mass of each gas was known, it was simply necessary to calculate the equivalent CO_2 mass using the PRG (Total Radiation Power) to obtain the carbon footprint of the explosives (by type, kg and MJ of explosive). The residual detonation components contributing to the greenhouse effect identified earlier are:

- CO_2
- NO_x (NO and NO_2)
- CH_4
- N_2O
- CO (which is not directly classified as a greenhouse gas but which tends to stabilise into CO_2 over time).

The results obtained are as follows: 1 kg of explosive produces on average 539 grams of CO_2 on explosive blasting and to produce 1 MJ of explosive energy, 141 grams of CO_2 will be emitted.

5.2 Results for quarries and sites

Calculating the carbon equivalent for explosives has enabled us to define the contribution of the overall drilling-mining station to CO_2 emissions for quarry and public works.

The carbon footprint for quarries includes:

- Internal transportation by dumper, shovels, loaders and the electricity consumption of crushers and conveyor belts.
- For the drilling-mining station: drilling, transport of cartridge explosives, the quantity of explosives, drilling machine transport, the mobile explosive manufacturing unit.

To go beyond the 'in situ' greenhouse gas emissions, it is helpful to look at the carbon footprint of stages prior to the activity of the quarry or public-works site itself, by considering:

- Ammonium nitrate production;
- Upstream diesel emissions;
- Construction of machinery and infrastructure.

Two types of rock are taken into account: hard

Table 1. Kg Carbon equivalent of greenhouse gases.

Gases	Kg carbon equivalent for 1 kg of gas
CO_2	0.273
Methane	6.27
N_2O	80.7
NOx	10.9
Dichloromethane	2.46
HFC - 125	764
HFC - 134	273
HFC – 134a	355
HFC - 143	81.8
HFC – 143a	1036
HFC – 152a	38.2
HFC -227ea	791
HFC - 23	2673
HFC- 236 fa	1718
HFC – 245 ca	153
HFC - 32	177
HFC -41	40.9
HFC – 43 – 10mee	355
Perfluorobutane	1909
Perfluoromethane	1309
Perfluoropropane	1909
Perfluoropentane	2045
Perfluorocyclobutane	2373
Perfluoroethane	2509
Perfluorohexane	2018
R11	1255
R12	2891
R134a	355
R22	464
R401a	307
R404a	1032
R407c	451
R408a	822
R410a	539
R502	1232
R507	1050
SF_6	6518

rock like granite and softer rock like limestone. This distinction is based on the different requirements in terms of drilling time and the quantity of explosive used.

- Drilling:
  - o 20 m/h for granite
  - o 30 m/h for limestone
- Explosives:
  - o 131 g/t for granite
  - o 100 g/t for limestone
- Electricity consumption (crushers):
  - o 2000000 kWh/year for granite
  - o 1400000 kWh/year for limestone

For electricity consumption, a distinction is drawn between quarries in France, where electricity production is mainly nuclear, which emits very little CO_2 compared with the European average based on gas, coal or oil. In France, one kWh electric results in emission of 0.084 kg of CO_2 equivalent, compared with a European average of an estimated 0.352 kg of CO_2 equivalent.

For public-works sites, the main differences are:

- A higher quantity of explosives because of the absence of a free face for blasting.
- A longer distance covered by the dumper compared with the average for quarries.

To summarise, the extraction of a tonne of hard granite-type rock in a quarry generates on average 3.53 kg CO_2 (4.87 in Europe because of the electricity production methods) and consumes 44.54 MJ.

To extract a tonne of hard limestone-type rock, a quarry produces on average 3.33 kg CO_2 (4.26 in Europe) and consumes 38.58 MJ.

For a public-works site, the maximum CO_2 emitted is 3.58 kgCO_2 with consumption of 55.6 MJ.

In terms of greenhouse gases, the drilling-mining station contributes about 10% of CO_2 emissions and explosives 2.5%.

In terms of energy, the drilling-mining station station represents no more than 6.5% and explosives less than 1.5% of total consumption.

6. RECENT RESEARCH DEVELOPMENTS : THE ECO-COMPARISON TOOL ECOFRO

6.1 Rationale and objectives

After the initial research in 2008, it became clear that a calculation tool enabling different configurations to be studied rapidly was needed.

As a result, in 2010, ECOFRO was born, an eco-comparison tool for fragmentation methods of

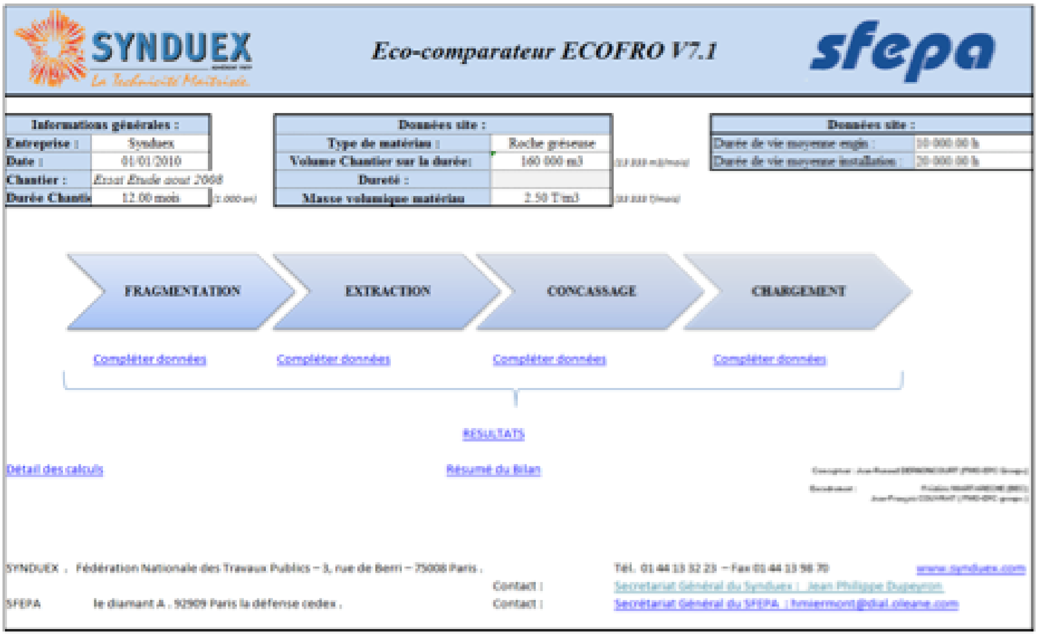

Figure 1. ECOFRO welcome page.

rock in quarries and on public works sites.

Developed in partnership with SFEPA, the union for manufacturers of explosives, powder and pyrotechnics, ECOFRO calculates not only greenhouse gas emissions according to a chosen method, but also the share of these emissions within the whole quarry or site. Moreover, this evaluation enables the effect of the fragmentation method on subsequent stages to be taken into account.

The comparison between different fragmentation methods is therefore made through different simulations taking into account the effects on subsequent stages.

The tool is based on websites belonging to the two unions, Synduex and SFEPA, and designed for contractors that specialise in drilling/mining, engineering firms, site superintendants, etc.

6.2 Instructions

ECOFRO is presented as an Excel spreadsheet that facilitates a chronological description of the quarry or public-works site. Results and reminders of the underlying assumptions during information gathering are given on the first two tabs. ECOFRO is an eco-comparison tool and therefore does not aim to give exhaustive carbon balances for quarries and public-works sites. However, the tool is not limited to describing and comparing fragmentation methods in terms of their greenhouse gas emissions; it also enables the impact of different methods on subsequent stages of the production process to be assessed. It therefore does enable changes to overall greenhouse gas emissions in a quarry or public-works site to be studied according to a chosen method.

On a first 'welcome' tab are given key facts about the quarry or public-works site: the volume extracted, lifespan of machinery and equipment, site name.

Four tabs then detail the work of the quarry or site in four successive stages of the rock treatment process:

- Fragmentation: choice of fragmentation method(s): drilling/mining, ripper, hydraulic rock breaker, planing machine
- Extraction: choice of machinery used to transport rock from the blasting zone to the crushing station, such as loaders, dumpers
- Crushing: two methods are proposed, electric and thermal (crusher with heat engine)
- Dispatching: transport of material to stores or direct loading of lorries.

For the fragmentation, several methods can be selected at the same time. For drilling/mining, details of the drill are needed: weight, motor

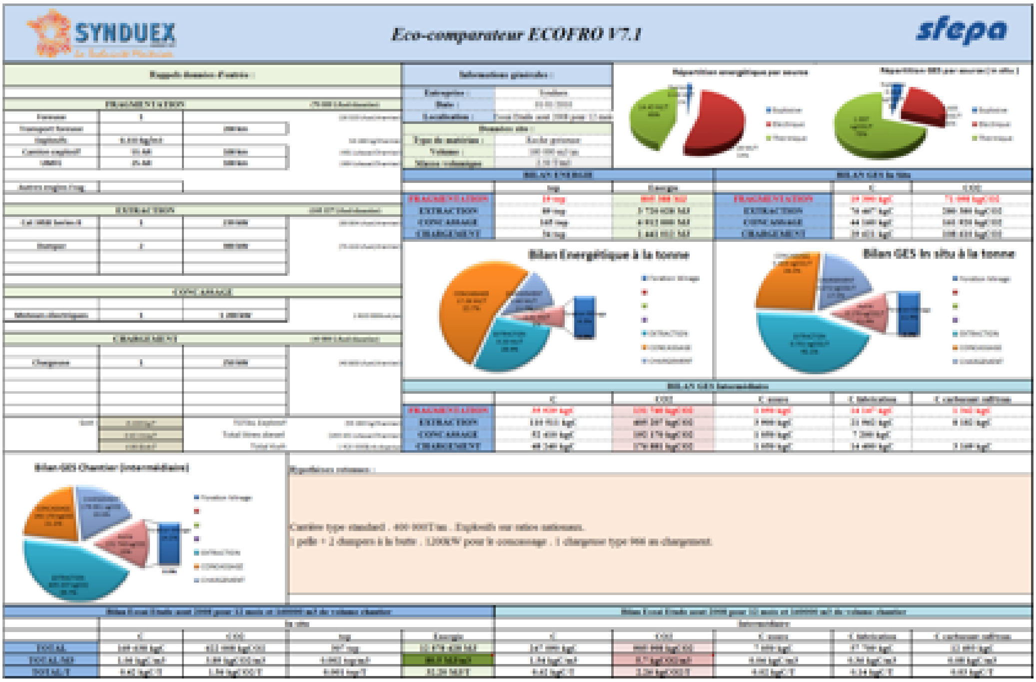

Figure 2. Example of results obtained by ECOFRO.

consumption or power, capacity, types of explosives used, the frequency of transport (for the drill and explosives), distance covered and the consumption or power of vehicles used.

The methodology is the same for the three following tabs: the weight, power or consumption of machinery, its output or duration in use will enable the fuel, kWh and steel needed to produce the plant and equipment to be obtained.

Based on the latter data (fuel volumes, kWh, quantity and type of explosives, weight of machinery and equipment), the greenhouse gas emissions can be calculated, using constants.

6.3 Constants

The value and origin of these constants are given in a separate tab. Three types of constant can be distinguished:

- Physical constants, established by definition;
- The French official data for calculating greenhouse gases emissions, as given in the Greenhouse gas emissions guide published by the Agency for the environment and energy efficiency (ADEME) in June 2010;
- Values obtained from the Synduex study of 2008. This research is the only attempt to evaluate the carbon footprint of explosives.

These constants are defined in the eco-comparison tool and cannot be modified by users. The tool has, however, been designed to enable the values to be updated because of changes to the ADEME guide or new research, particularly experiments on emissions from detonation of industrial explosives.

6.4 Calculations

The detailed calculations made by ECOFRO can be consulted in the Calculations tab. These cannot be modified by the user but explain the origins of the values subsequently given.

6.5 Results

Once the necessary information has been obtained, two tabs describe the results of the simulation.

The first tab presents:

- A summary of the elements of the quarry or public-works sites that were initially chosen.
- A breakdown of energy used at the quarry or public-works site by origin: thermal, electric and explosive.
- A breakdown of greenhouse gas emissions

according to the different rock treatment phases: fragmentation, extraction, crushing and dispatch.
- Energy consumption and greenhouse gas emissions for different stations and the overall site are given in tonnes.

The second tab gives the general data, assumptions made for the simulation and the principal data, therefore enabling it to be compared with another simulation. ECOFRO aims to facilitate this comparison via energy consumption and source (and therefore energy efficiency) and therefore via the comparison of overall emissions of the quarry or public-works site.

6.6 Future development of the tool

ECOFRO is designed to be an evolving eco-comparison tool:

- The database of site equipment and its characteristics is not fixed. It is therefore possible to add new models, types of machinery and above all the user can change the inputs for consumption. This enables it to take into account ageing of the equipment, specific environmental conditions and the continual modernisation of site machinery and therefore its energy consumption.
- The constants used for calculations can be changed rapidly by an administrator and all the calculations will then be updated. This will modify the tool in line with future editions of the ADEME greenhouse gas emissions guide and advances in obtaining carbon equivalents for explosives.

7. ENVIRONMENTAL IMPROVEMENTS TO DRILLING/ MINING

Synduex currently envisages two main areas of development concerning the environmental impact of explosives in quarries and public-works sites. The first falls within ‘technology management’ and consists of developing an analytical, comprehensive comparison tool for the environmental impact of the rock fragmentation phase. The second is based on the hypothesis that an increase in the explosive energy during blasting can affect the overall emissions balance of the system in question.

7.1 A comprehensive comparison tool

Synduex hopes to extend the ECOFRO tool to evaluate the different environmental pollution that explosives or any other rock fragmentation method can cause. In its current stage, ECOFRO studies greenhouse gas emissions and the energy eficiency of fragmentation, but a more comprehensive tool would look at recognised, ‘classic’ pollution: dust, vibration but also the growing constraints in regulation such as excessive acoustic pressure.

7.2 Greater energy efficiency

The second area originates in the theory that the ‘quality’ of blasting has an influence on subsequent stages of rock treatment. In other words, using extra explosive energy to improve rock fragmentation can have significant consequences for the rock extraction and crushing.

This potential area for improvement requires on-site experiments to assess its validity, but it makes sense to formulate some working hypotheses:

- Better rock fragmentation and therefore more regular grading of the blasted rock (fewer large and small pieces) would facilitate extraction because the loader bucket and the dumper would be loaded better, the work of the shovel and loader would be simplified in the absence of large blocks of rock that require greater manipulation by the machinery, and therefore use less fuel per tonne produced and reduce greenhouse gas emissions.
- This same more regular grading will facilitate the work of the crusher(s). The absence of large rock pieces will save important mechanical work and avoid halts to production. The attrition effect will also improve the efficiency of the crusher and reduce the replacement parts needed for equipment. This improvement should reduce energy consumption per tonne.

Estimates based on these hypotheses help give a picture of the effects of additional explosive energy during blasting on the quarry’s carbon footprint. The results take into account the above mentioned reductions but also the additional emissions from the extra explosives and associated drilling for installation and manufacturing of the explosives.

The estimated reductions for subsequent stages after blasting are still to be validated. However, based on these estimates, a 50% increase in the explosive energy (from an average of 300 g/m^3 to 450 g/m^3 of explosives) would reduce overall

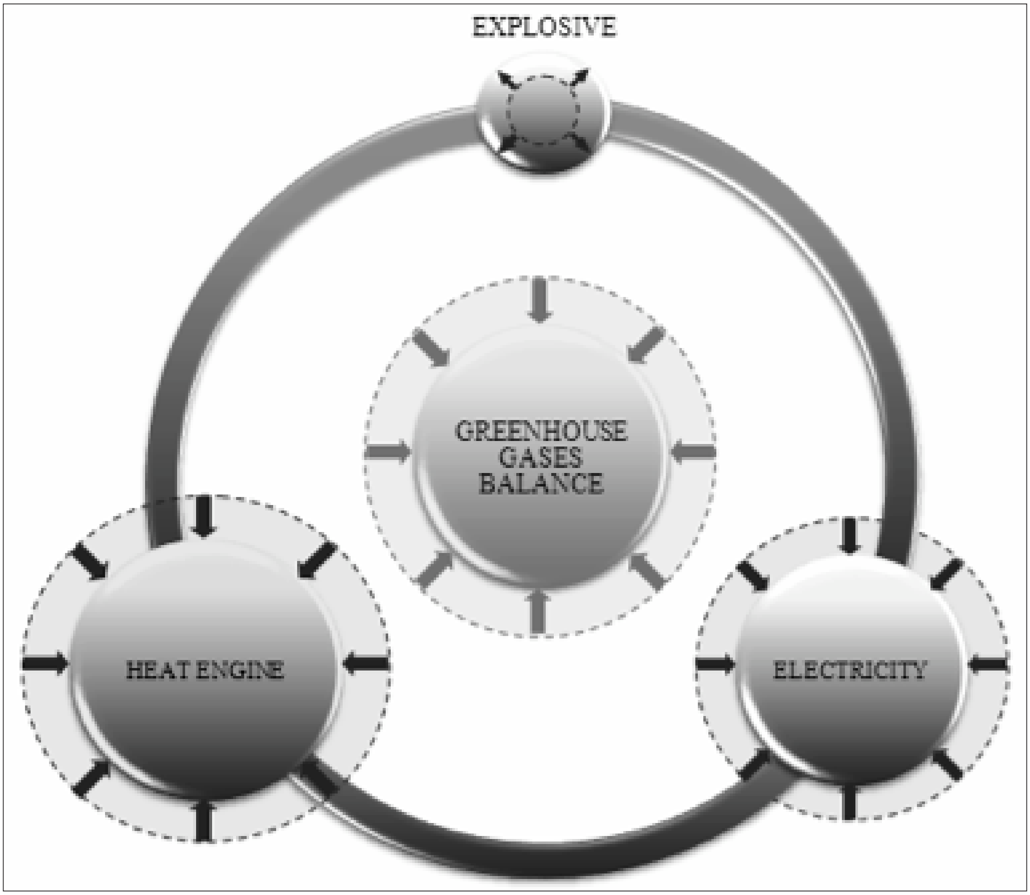

Figure 3. Energetic impact of explosives and interaction between type of energy.

greenhouse gas emissions for quarries and public works sites by between 4% and 6%.

This energy efficiency would enable production in France of heavy rock aggregates, which is estimated at 250 million tonnes/year entailing greenhouse gas emissions of about 750 million kg CO_2, to make savings probably greater than 45 million kg CO_2. Moreover, the advantages of better use of explosives could be even greater in other countries that do not have low-carbon electricity.

Appropriate use of explosive energy could therefore enable an overall reduction in greenhouse gas emissions by means of a substantial cut in thermal and electric energy consumption.

8. CONCLUSION

The research carried out by Synduex shows that, contrary to received ideas, drilling/mining is a fragmentation method that produces little pollution, particularly in terms of greenhouse gas emissions.

The use of explosives is a very efficient way to break rock. Its high energy potential is seen in microseconds during the reaction known as a 'detonation', in which the initial conditions (thousands of degrees and bars) enable maximal energy to be released from the molecules involved. In addition to the high output of this chemical reaction, mining has the advantage that it releases energy at the very heart of the rock and therefore avoids the losses caused by superficial fragmentation operations.

In the race to reduce greenhouse gas emissions, improve energy efficiency and minimise the environmental impact, drilling/mining has several strengths which make it the most efficient rock fragmentation method and the best in terms of sustainable development.

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Blasting for environmental remediation

J. Wallace & Q. Rhoton
Wallace Technical Blasting, Inc. Woodland, Washington, USA

ABSTRACT: Over the past century, well-intentioned industrial projects have turned out to have negative impacts on the environment. Three projects demonstrate that blasting can be an effective tool in environmental remediation:

1. The Atlas site in Washington State, USA, was a former explosives manufacturing site that was now a potential rail/trucking transfer site. Shaped-charges were fired to detonate any residual pools of nitroglycerine.
2. At the Tulana Farms site, Klamath Lake, Oregon, USA, levees were built over 50 years ago to create 3500 hectares of additional farmland from the shallow lake bed. The resulting loss of habitat had a serious detrimental effect on two species of fish. Drilling and systematic blasting of 3.2 kilometers of levees using 100,000 kg of explosives successfully restored the wetlands.
3. The century-old hydro dam at the Willamette Falls in Oregon City, Oregon, USA decimated juvenile fish (including endangered salmons and lamprey) migrating to the ocean. Remediation blasting removed a portion of the top of the dam allowing installation of inflatable bags that can be deflated during downstream migration of the fish.

Results were positive for all three projects.

1. INTRODUCTION

Over the course of the past century industrial projects thought to be worthwhile have turned out to have negative impacts on the environment. Blasting with explosives is a tool that can be used to remediate those negative impacts as old sites are cleaned up or at least rendered less toxic or hazardous. This paper discusses three projects which demonstrate the successful use of explosives in environmental remediation.

2. EXPLOSIVES MANUFACTURING SITE CLEANUP

The Atlas site is located in a rural area of the Puget Sound region, Location 1 in Figure 1, of Washington State, USA, south of Seattle. This former explosives manufacturing plant was shut down in the 1960s. The buildings had been burned and the foundations buried under approximately 2 meters of the local alluvial gravels. Four decades later the site was identified as the desired location for a rail/trucking

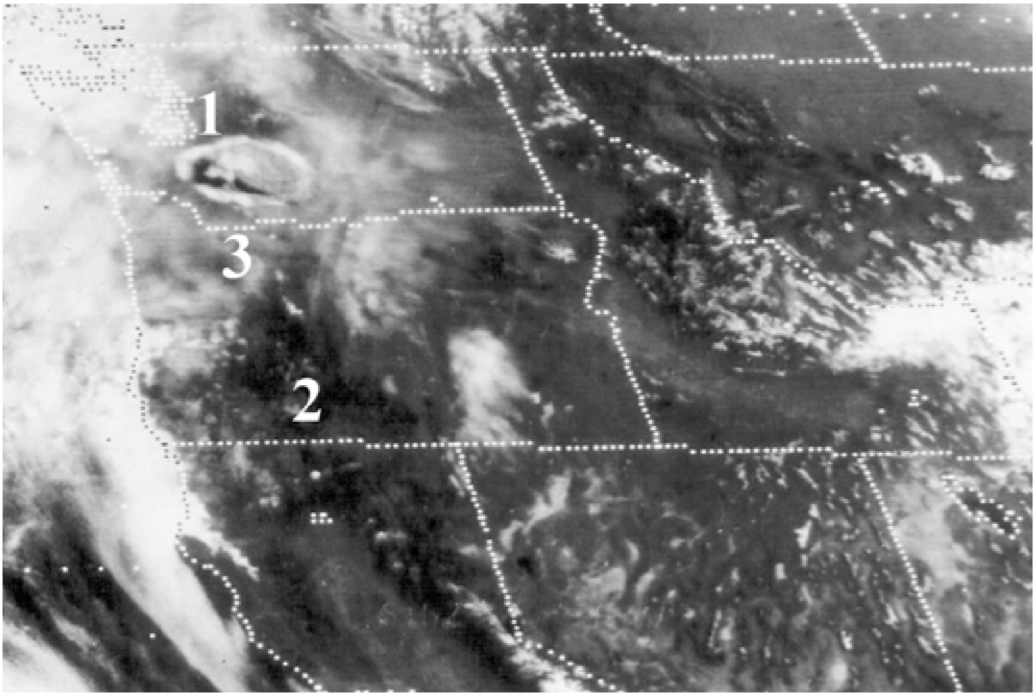

Figure 1. Jobsite locations (NASA photo taken during eruption of Mt St Helens, 1980).

transfer site due to growing international trade through the Puget Sound-Pacific Ocean ports.

Site planners raised concerns that residual nitroglycerine (NG) might still remain in several areas. Due to the hazard that such residual NG might pose to new construction at the site, the owners engaged an environmental firm to conduct a cleanup effort. Methods for neutralizing the NG were weighed and the chosen approach included blasting in 6 identified suspect areas in an attempt to detonate any pools that might remain at elevations that would pose a risk. Our firm was hired to perform that blasting.

Fortunately good records existed regarding former building locations and elevations. That allowed the environmental contractor to excavate the alluvial gravels that had been placed atop the foundations down to a safe distance above suspected NG pools, and to expose the old concrete foundations.

The selected blasting method was to place shaped charges in patterns, Figure 2, on the surface above suspected NG pools. The charges would have enough directed energy to detonate any NG within 1.5 meters of the surface. Major concerns were the unknown quantity, if any, of NG that might remain in the suspect areas, and the size of any secondary blast that might result. Additionally, since the shaped charges would be fired on the surface, air-overpressures were a concern even though the location was rural.

Air over-pressure and vibration monitoring points were established near the property limits and a security plan put in place to ensure that off-road vehicle riders who frequently trespassed on the property would not be endangered. Charges were placed and individually fired so that responses could be monitored and measured. Fortunately weather conditions (primarily snowing heavy wet flakes) were favorable for our work, both from a security standpoint and for dampening air-overpressure.

None of the blasts triggered secondary explosions, Figure 3. It was concluded that the great depth of the alluvial gravels underlying the site combined with the significant annual rainfall of over 1.5 meters per year had washed any residual NG down into the gravels below the depths that our charges could effect, and below any depth that would be disturbed during construction of the new

Figure 2. Shaped charges placed around exposed foundations.

facility. The site is now ready for new construction.

3. TULANA FARMS LEVEE BREECH

The Tulana Farms, Location 2 in Figure 1, site is located in southern Oregon, USA. Over 50 years ago the site was increased in sized by approximately 3500 hectares through dredging and building dikes within the shallows of Klamath and Agency Lakes. At the time this was considered a positive move to increase the availability of rich farmland. Much of the new land was settled by Czech refugees from WW2.

Over time however it became evident that the reed-filled shallows that had been turned into farmland had been critical habitat to survival of juvenile fish of two species that were important food sources to the aboriginal Native Americans. Additionally it was found that due to the short growing season at the 1300+ meter elevation farming was only marginally profitable at best. A non-profit environmental group purchased the site with the intent to remove the levees and restore the critical habitat for the endangered fish, Figure 4.

The material used to build the levees were lake-bottom soils, sands and especially peats. It quickly became evident to the excavating contractor engaged to remove the levees that mechanical means of removal were impractical and hazardous due to the instability of these materials, Figure 5. Test blasting of a short stretch of an interior levee proved the concept that blasting was both a practical and cost-effective method of removal.

A plan to remove a total length of 3.2 kilometers of levee at 4 locations, Figure 6, was made based upon hydraulic studies from the owner showing that removal of that length would allow proper seasonal water flows to ensure a healthy fish habitat.

Drilling was accomplished from on top of the levees using an auger-type drill to a depth of 3.5 meters, drilling from atop the levees. Degradable plastic pipe hole liners were installed, capped at the bottom to keep the peat/silt from re-entering the hole from the bottom. The liners were also secured to stakes at the top so that water pressure from below did not eject them over time. A total of 2900 holes, 150 mm diameter, were drilled in 5 rows, Figure 7. The 3.2 kilometers of total breach was divided into 4 segments of nearly equal length

Figure 3. Post-blast photo showing depth of blast effects in alluvial gravels.

Figure 4. Mature size endangered fish, one of two affected species.

Figure 5. Liquefaction of levee materials from simple excavation vibrations. Note sinkage of excavator.

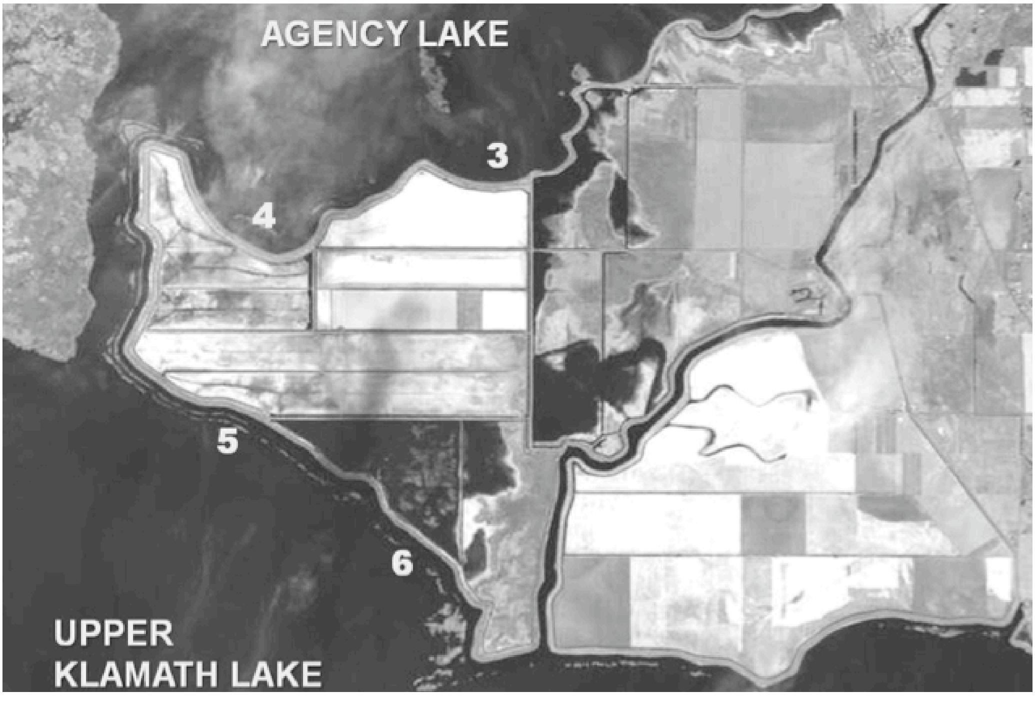

Figure 6. Aerial view showing the location of four planned breach locations (3, 4, 5 & 6).

Figure 7. Auger drill working, note the installed blasthole liners in the foreground.

and hole count, separated by sections of levee to remain as per the hydraulic recommendations.

A very restricted time-window was allowed for blasting due to fish and water fowl considerations. Late October was selected. That put the blast loading and firing time into inclement weather season which included rain and snow, conditions that seriously hampered operations. Notwithstanding the challenging weather all 2900 holes were loaded using water resistant ANFO as the main charge. Fortuitously, the day of the blast included fair weather, Figure 8. The owner expected about 40 spectators. However over 200 people, mainly supporters of the project, showed up and watched the successful blasting from a safe location, Figure 9.

The endangered fish have returned to the restored habitat. In addition waterfowl now also use the restored wetlands as their winter resting grounds, Figure 10.

4. DAM-TOP REMOVAL, FISHWAY IMPROVEMENT

The hydro dam and power generating station at the Willamette Falls, Figure 11, in Oregon City-West Linn, Oregon, USA, Location 3, Figure 1, was built over a century ago. This historic dam and power generating station was the starting point for one of the earliest long distance electric transmission lines. It became evident early on in the history of such dams in the Pacific Northwest that they blocked the upstream migration of adult salmon, Figure 12, enroute to their spawning streams. Fish ladders, manmade detours for the returning adult salmon, were constructed at most dam sites.

Figure 8.

Figure 9.

Figure10. Waterfowl in reclaimed wetlands, between breeches 3 & 4.

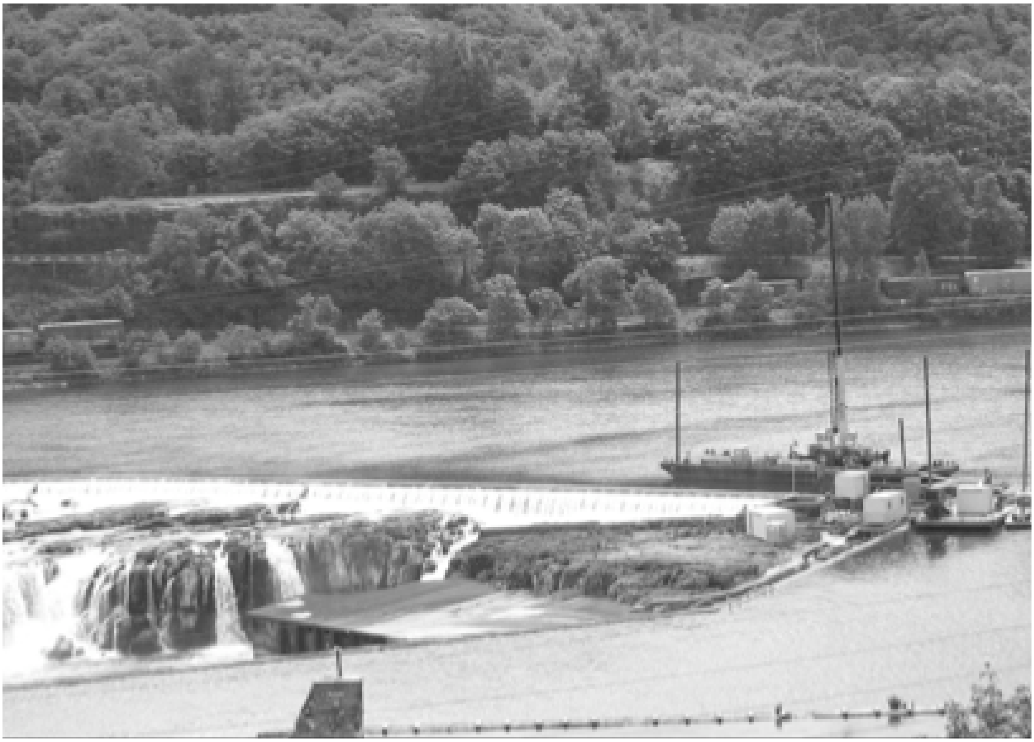

Figure 11. Willamette Falls, Oregon.

Figure 12. Mature 32-kg female Chinook/King Salmon.

Unfortunately little thought was given to the downstream migration of the smolts, the small salmon in the 50-75 mm size range that are heading out to the Pacific Ocean to live and grow for several years before returning to spawn. It has since been calculated that as many as 90% of the small fish that mistakenly take the downstream route through the power generating turbines are killed in the process. Alternative methods are now being devised and implemented on many dams in the region.

On Willamette Falls project a portion of the top of the dam that ran along the top of the falls was removed by blasting, Figure 13 a & b, and replaced by an inflatable section that could be deflated during the traditional times that the young salmon are migrating towards the ocean. This allows these small, fragile fish to swim down their age-old route, over the natural falls.

Due to the very brief time window between upstream migrations and downstream migrations, blasting was the method of choice since mechanical methods could not have accomplished the work within the time frame allowed for construction.

Figure 13a. Loading blast inside cofferdam.

Figures 13b. Post-blast results.

Figure 14a. Installing inflatable top.

Figure 14b. Water flowing over deflated bags during migration time.

A cofferdam was installed to protect the work area. Great care had to be taken not to damage the cofferdam while blasting within 1 meter distance. Additional blasting to reduce blocking obstacles took place within the channels down through the falls.

The finished project won awards for innovation in design and construction, Figures 14 a & b. Full details on salmon survival have yet to be tallied given the short time since construction was completed but preliminary reports are encouraging. A near-record run of adult salmon is forecast this year. These returning adults represent the first cohort of juveniles whose downstream journey took place after the reconfiguration of the dam.

5. CONCLUSION

The judicious use of explosives can be a worthwhile, cost-effective and time-efficient tool in environmentally sensitive projects, projects that have ongoing positive environmental consequences.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the following people and agencies for their contributions to this paper: Technical Support, Mr. Tobias Wallace & Mr. Tyonek McAdams; Editing, Ms Susan McAdams; Tulana Farms Project, Mr. Warren Olson & CNN; Willamette Falls Project, Baseline Industrial, Inc., Mr. Mark Aldridge.

REFERENCES

Rhoton, Q. 2010. Levee Removal by Explosives, Upper Klamath Lake, Oregon, *Proceedings of 2010 ISEE* Conference.

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Environmentally conscious blasting: beyond mine-to-mill

E. Sellers & X. Gumede
AEL Mining Services, Johannesburg, South Africa

ABSTRACT: A model is being developed to quantify the benefits for mining companies from the reduction in greenhouse gas and energy consumption by the application of innovative blast designs in addition to direct financial benefits throughout the mine-to-mill value chain. The conversion from shock tube initiation systems to electronics and some changes to powder factor measured on three open pit mines had previously been used to show significant improvement on blast outputs. Benefits were realised on drilling, blasting, loading, hauling and beneficiation. Quantification of the benefits of reduced greenhouse gasses are investigated in this study. The study has highlighted new data that must be recorded and hence some assumptions were made as to fuel consumptions and the energy in crushing was obtain form the Bond work equation. The two typical mine to mill projects. an aggregate quarry and open pit platinum mine, produced energy savings and reduced greenhouse gas emissions associated with the careful application of use of explosives and controlled timing. The model provides a new insight into how project feasibility should be decided based on economic and environmental viability. However, a less-fines project in a cement limestone mine required coarser fragmentation leading to apparently increased energy consumption and GHGs. More work is required to identify opportunities for energy saving in the less-fines scenario.

1. INTRODUCTION

The debate around global warming has highlighted how industrial activities can affect the planetary climate and has increased the desire of mining companies to minimise their environmental footprint. As the population expands mining occurs more frequently in peri-urban areas where consideration of noise, air and water pollution is vital. Much work has been done to develop international standards to measure the gas emission of various processes including those from blasting (Kutz 2010). However, the understanding of measures that can improve the situation of a given mine have lagged behind.

In addition, the increasing scarcity of resources implies that there are constraints to production based on the lack of fundamental process requirements such as electricity supply. South Africa supplies about two thirds of the electricity for the African continent, but by 2007, the potential national electricity demand was running within 8% of total installed capacity (Eberhard *et al*. 2008). Despite the reintroduction of mothballed power stations the country has implemented system management measures to shed excess electrical load and hence created rolling blackouts. These are highly inconvenient to processing plants and cause a loss of production and profitability. As part of a demand side management programme, industries have been requested to save power where possible (Mlamo-Ngcuka 2004). These issues will affect more countries in the future.

Improved blast design procedures that indicate consciousness of the environment have been presented previously. There is considerable literature on noise and vibration abatement (Spathis 2010 and many others). The airblast nuisance (Sellers *et al*. 2011) and the safety concerns around flyrock have led to predictive formula (Richards and Moore 2008). Air pollution from dust is also being studied (Scott *et al*. 2010). Water pollution from the blasting agents is also an issue being addressed (Sprott *et al*. 1997). More recently, work on the quantification of greenhouse gas emissions has been presented (Brent 2010). The mine-to-mill concept has been characterised in the blasting literature as a method for increasing profitability so that improved blast results can add value to mine operations (Workman and Eloranto 2003). Little has been said on the topic of the direct environmental benefit of reduced energy consumption. Successful implementation of blasting improvement plans, introduction of electronic detonators, selection of more appropriate explosive products have all been shown to decrease the energy requirements in the load - haul – crush – mill cycle. In the new era, these concepts must be revaluated in terms of the triple bottom line that considers the people, the planet and the profitability.

In this work we have critically reassessed a number of mine-to-mill projects completed by the company in order to identify where the blasting can improve the carbon footprint and save electricity. We understand that different mining operations have specific process needs and that these vary between their waste and ore operations. To some mines improved fragmentation is preferred through more cost effective beneficiation process. In others, fines constitute significant revenue losses in which case a coarser material is preferred. We have developed a simple model to relate the change in blasting parameters to the savings in energy consumption, electricity demand and greenhouse gas emissions. At this stage a number of simplifying assumptions are made to grapple with the concepts and to identify the main drivers and trends. The model is described and quantitatively applied, with some assumptions, to evaluate three case studies of diverse mining operations – a quarry, a large platinum mine and a lime producing mine - as a first step on the route to a more generic optimisation process that considers all environmental aspects of the blasting process.

2. MODEL

The model deconstructs the mine-to-mill value chain activities and parameters which include the bench geology, blast design, muck pile and fragmentation results, loading, hauling and beneficiation efficiencies. Throughout this process the blast outputs from different blast design or initiation systems are compared. All energies used within the mine-to-mill value chain are then determined. The fragmentation result for the base case is compared with the results after the blasting improvement programme and the energies used in delivering the final product are quantified. The important relationships and assumptions regarding inputs are discussed below.

2.1 Explosive energy and carbon rating

The primary energy used to break the rock from large blocks to correctly sized fragmentation is explosives. The total amount of explosives used was calculated from the annual tonnages blasted as follows:

Total Explosives used (tons) =

$$\frac{\textit{Annual production (tons) x powder factor (kg/ton)}}{1000} \qquad (1)$$

Brent (2010) noted that for ANFO comprising 6% diesel fuel by mass, the carbon content is 52.1 kg/t ANFO. Thus, carbon emission of ANFO is 191 kg of carbon dioxide equivalent (kgCO2-e) per ton of ANFO, which approximates to 1 ton of emissions per 5 tons of explosives. For AEL ANFO, using the VIXEN-I code (Cunningham *et al*. 2008) the total percentage of carbon is calculated as 43 kg per ton of ANFO resulting in an emission of 156 kgCO2-e per ton. The equivalent for doped emulsions is about 131 kgCO2-e per ton. Company official values range from 166.3 kgCO2-e per ton to 177.8 kgCO2-e per ton for ANFO and Heavy ANFO (Van Dongen 2011, personal communication).

An equivalent method is to use the end concentrations of the detonation products and include their Global Warming Potential (GWP) factors. Table 1 shows the results of gas concentration calculations for ANFO. The mass of

Table 1. Gas concentration calculations for ANFO per kg of explosive.

Gas	End Isentrope Concentrations (mole/kg)	g/mol	g/kg	kg/1000kg	GWP	t-CO2e/t
CH4	0.18269	16	2.9	2.9	25	0.073
CO	0.001		0	0		
CO2	4.12251	44	181.4	181.4	1	0.181
H2	0.23412		0	0		
NH3	0.00509		0	0		
H2O	26.98518		0	0		
N2	11.74276		0	0		
Total				184.3		0.254

gasses with global warming potential are calculated per kg of explosive. The GWP factors for 100 years (Wikipedia 2011) are used to calculate the equivalent carbon emission resulting in a higher value of the carbon emission due to the high weighting of the methane. Brent (2010) considers this to be spurious as the methane will most likely burn and convert to CO2 during the blast anyway. The higher value of 0.25 kgCO2-e per kg of explosives was used for the surface bulk product in this study.

2.2 Fuel and carbon rating

Diesel is used during drilling, loading and hauling. The fuel consumption rates need to be obtained for the different equipment used during drilling, loading and hauling. Kecojevic *et al.* (2010) show how fuel consumption depends on the engine size, the working conditions and between drivers. Many mines have a variety of models of equipment doing each of the activities. In our model therefore, typical values are selected based on a single type of equipment with consumption values determined to be in the correct range based on information from the mine, the manufacturer and the web. The amount of fuel used during drilling, loading and hauling was calculated from the following:

Drilling diesel amount (Dd) =

$$\frac{\text{Total Holes Drilled x Consumption rate (L/hr) x Hole depth (m/hole)}}{\text{Drilling rate (m/hr)}} \quad (2)$$

Loading diesel amount (Dl) =

$$\frac{\text{Total tons loaded x Consumption rate (L/hr)}}{\text{Loading rate (tons/hr)}} \quad (3)$$

Hauling diesel amount (Dh) =

$$\frac{\text{Total production hauled (tons) x Consumption rate (L/hr)}}{\text{Hauling rate (tons/hr)}} \quad (4)$$

Combining equations (1) to (4) provides the total fuel consumption.

$$Dt = Dd + Dl + Dh \quad (5)$$

Then, the total carbon equivalent is calculated as:

$$Tc = Dt * Cr \quad (6)$$

where Cr is an average carbon rating for the diesel fuel that will vary from country to country. For this study, an average Cr equalling 2.5 kgCO2-e per litre was applied (Coe 2005).

2.3 Electric energy and carbon rating

Many larger mines use electric or electricity enhanced machinery for drilling, loading and hauling. Information about the actual power consumption has not been provided and so we assumed that the maximum rated power is applied. For example, the total annual, maximum power consumption for an electric drill can be calculated as:

Em (kWh/a) =
P (kW) * holes drilled per annum (7)
* hole length (m) / drilling rate (m/hr)

Where P is the maximum rated power of the engine. During the beneficiation process the further processing of blast output to the final product involves the use of electrical energy. Many mine-to-mill studies only produce percentage enhancements of crusher efficiency and the absolute power demand is not noted. In these cases, the third theory of comminution developed by Bond (1952) is used to estimate the energy consumption during beneficiation. The theory requires that an 80% feed size and 80% product size is used in the calculation of work output. The following is the Bond equation used.

$$W = 10W_i\left(\frac{1}{P^{0.5}} - \frac{1}{P^{0.5}}\right) \tag{8}$$

Where:

W = *work input,kWh/Ton*

= *work index for the specific rock type, kWh/Ton*

P = *80% passing size of the product*

F = *80% passing size of the feed*

According to Nielsen and Kristiansen (1996) there is evidence that the Bond work index is significantly reduced by heavier blasting. In Bond's work (1952, 1961) the Taconite rock has a work index of 14.87 kWh/ton that is reduced to a work index of 10.4 kWh/ton with explosives induced fragmentation reduction from 80% passing 40cm to 80% passing 30cm. If a linear relationship is assumed and rock type effect is not considered it can be shown that the work index will change by 0.45 kWh/ton per centimetre size change. The work index Wi has been measured and reported for many rocks. The published Bond W_i for different rock types was used for the three rock types used (Bond 1952, 1961). Where the actual rock type was not available in the published work index list a closest rock in terms of geological characteristics was considered. Costs used for electrical energy was obtained from a study that was done at Eskom by Gumede (2007). Revenue losses due to coal quality indicated the cost to be $0.101 per kWh, which compares with figures given on Wikipedia.

The total electricity used per annum by crushing or milling is then estimated as:

$$Ec\ (kWh/a) = Wi\ (kWh/ton)\ \times \underline{TPC} \tag{9}$$

Where TPC is the total production crushed (tons/annum). To add the benefit of increased throughput due to blasting improvements without having all the crusher data, the total throughput for the new case is factored by the change in throughput:

$$TPC\_new = TPC\_old*CT\_old/CT\_new \tag{10}$$

where CT_old and CT_new are the crusher throughputs in t/hr for the old and new cases.

The total carbon rating for electricity usage depends on the country in question and can be determined from the national value. In South Africa, the average emission factor is 1.015 kg CO2-e/kWh (Letete *et al.* 2010)v

3. CASE STUDIES

Three cases studies of diverse mining operations – a quarry, large platinum mine and a lime producing mine were investigated as a first step on the route to a more generic optimisation process that considers all environmental aspects of the blasting process.

3.1 Quarry

Rooikraal quarry, situated 56km south-east of Johannesburg, produces approximately 40,000 tons of dolerite per month (Pitchford and Moeller 2007). The shock tube initiating system that was previously used had limitations regarding fragmentation uniformity and muck pile profile due to lack in delay timing precision. The conventional shock tube initiating system was replaced by AEL's electronic detonating system, but the drill and timing pattern were left unchanged. This study evaluates absolute benefits obtained from more accurate electronics delay detonators. The results obtained revealed that the total mining cost was increased by 2 % while the drill and blast cost per hole increased by 8%. The productivity of earth moving equipment increased by 24.7 % and the crusher throughput went up 14.7 %. The operation saved $100,000 per annum however this excluded the carbon credits and other GHGs related benefits. With the electronics precision delay timing fragmentation is greatly improved, directly improving numerous down-stream processes. With the focus on GHGs generated throughout the mine-to-mill value chain and the benefits from savings thereof the energies used in various stages were determined. The quantities of GHGs from various stages were summed up to calculate the total carbon footprint as shown in Table 2. Fragmentation improvements

Table 2. Quantification of benefits at Rooikraal quarry.

			Values / Description			
Category	**Item**	**Units/Description**	**base case**	**Improved**	**Change**	**%Change**
Bench Geometry, Geology and Production	Annual production (Ore &Waste)	tons	50000000	50000000		
	Monthly production (Ore)	tons	425000	425000		
	Total Holes drilled annually		15617	29579		
	Average explosives used per month	tons	23138.2	43823.3	20685	89%
	Bench Height	m	15.0	15.0	0	
	Rock Type	Platreef	Platreef	Platreef	0	
	Ore/Waste	Ore/waste	Ore/waste	Ore/waste	0	
	Rock Density	tons/m^3	2.9	2.9	0	
	Rock Index (Wi)	kWh/ton	24.22	19.7	0	
	Rock Mass Rating		Hard rock	Hard rock	0	
	Hole Depth	m	15	15	0	
Blast Design Input Parameters	Explosives type		emulsion	emulsion	0	
	Explosives Density	g/cc	1.3	1.3	0	
	Initiation system		S/Tube	EDD's		
	Burden	m	8	5.8	0	
	Spacing	m	9.2	6.7	0	
	Hole diameter	mm	311	311	0	
	Inter-hole timing	ms	17	41		
	Inter-row timing	ms	42	70		
	Stemming length	m	5	5		
	Overall Powder factor	kg/m^3	1.00	1.90		
Drilling	Drilling Rate	m/hr	15	15		
	Electricity Consumption	kWh	16310594.7	30891913.8		89%
Fragmentation	P50 Size (Ore)	cm	14.0	7.2	-6.8	-49%
	P80 Size (Ore)	cm	38.0	18	-20.0	-53%
	Top Size (Ore)	cm	110.0	60	-50.0	-45%
Loading	Bucket size	m^3	26.00	26.00	-	-
	Loading rate	tons/Opr hrs	3300	3800	500	15%
	electricity consumption	kW	1680	1680		
	electricity	kWh/annum	25454545	22105263	-3349282	-13%
Hauling	Haul Truck Capacity	tons	136.00	136.00	0	
	Haul fleet production rate	tons/hr	3300	3500	200	6%
	Haul fleet production rate (Ore)	tons/hr	3300	3500	200	6%
	Haul fleet production rate (waste)	tons/hr	3300	3500	200	6%
	Hauling Fuel Consumption	l/hr	100	100		
Beneficiation	Primary Crusher Production Rate	tons/hr	148.00	170	22.00	15%
	Primary Crusher feed Size	cm	38.00	18	-20.00	-53%
	Primary Crusher Product Size	cm	10.20	10.20	0.00	0%
	Secondary Crusher Product Size	cm	1.9100	1.91	0.00	0%
	Grinding / Final Product size	cm	0.0053	0.0053	0.00	0%
	Blasting Work Input	kWh/ton	0.2700	0.24	-0.03	-11%
	Primary Crusher Work Input	kWh/ton	0.3655	0.116	-0.25	-68%
	Secondary Crusher Work Input	kWh/ton	0.9941	0.6157	-0.38	-38%
	Grinding Work Input	kWh/ton	31.516	25.635	-5.88	-19%
Carbon Rating	Explosives	kgCO2-e/kg	0.25	0.25		
	Diesel	kgCO2-e/l	2.5	2.5		
	Electricity	kgCO2-e/kWh	1.08	1.08		
Energies	Total Explosives	kg/annum	277658623	525879429	248220807	89%
	Total Fuel used	litres/annum	1515152	1428571	-86580	-6%
	Total Electricity used	kWh/annum	209431865	170063982	-39367882	-18.8%
Carbon FootPrint	Explosives	kgCO2-e/annum	69414656	131469857	62055202	89%
	Fuel	kgCO2-e/annum	3787879	3571429	-216450	-6%
	Electricity	kgCO2-e/annum	226186414	183669101	-42517313	-19%
	Total	**kgCO2-e/annum**	**525575362**	**502379488**	**-23195874**	**-4%**
Annual cost	Drilling	$	-	-	-	-
	Blasting	$	-	-	-	-
	Loading	$	$2 570 909.09	$2 232 631.58	-$338 277.51	-13%
	Hauling	$	$1 704 545.45	$1 607 142.86	-$97 402.60	-6%
	Beneficiation	$	$21 152 618.32	$17 176 462.23	-$3 976 156.09	-19%
	Carbon footprint (Carbon tax)	$				
	Total Cost	$	**$25 428 072.86**	**$21 016 236.67**	**-$4 411 836.19**	**-17%**

associated with the introduction of electronics delay detonators were measured and associated electrical energy consumption measured as well as fuel consumption from loading and hauling.

3.1.1 Blasting

A total explosives amount of 141 986 kg was used in the production of 480,000 tons of ore. At a carbon footprint rating of 0.25 CO2-e/kg a total carbon footprint of 35 496 kg was calculated. Since for both blasting design the same powder factor was used there was no carbon footprint savings in this activity.

3.1.2 Loading

Loading improved from 291.6 tons per hour to 321.9 tons per hour. Keeping the loading fuel consumption rate constant at 6 l/hr the total fuel used during loading improved from 9,875 l to 8,946 l per annum. At a carbon footprint rating for diesel of 2.5 CO2-e/l a total savings of 929 Kg was achieved.

3.1.3 Hauling

Hauling improved from 146 to 182.2 tons per hour. Keeping the hauling fuel consumption rate constant at 11.5 l/hr the total fuel used during hauling improved from 37,808 to 30,313 l/annum. At a carbon footprint rating for diesel of 2.5 kgCO2-e/l a total savings of 18 738 kg was achieved.

3.1.4 Beneficiation

From fragmentation results the primary crusher feed size improved from 24.71cm to 14.83 cm. Dolerite is geologically associated with Gabbro and Basalt. Gabbro is a coarser version of Dolerite and it has a work index of 18.45 kWh/ton, the finer version is Basalt which has a work index of 20.41kWh/ton. For the purpose of this study a work index of 19 kWh/ton was chosen for Dolerite. Considering the size reduction of 9.88 cm and assuming a linear decrease of the work index as discussed, the work index for the rock will improve from 19 kWh/ton to 14.5 kWh/ton. Based on these results the total electrical energy used to reduce the particle from a feed size of 24.71 cm to a final product size of 0.0053 cm improved from12,343,816 kWh to 10,783,761 kWh per annum, with a total electrical savings of 1,560,054 kWh per annum and a carbon footprint equivalent savings of 1,684,858 kg's.

3.1.5 Benefits summary

The results showed an annual reduction of carbon footprint of 6,634 kg from loading and hauling (4.43 % reduction), 1,684,858 kg (12.64 %) from electrical energy use. The total carbon footprint savings were 1,691,492 kg per annum (12.51% reduction). The monetary value associated with the equivalent electrical and fuel reductions is $167,043.00 per annum, which is a 12.8 % improvement.

3.2 Large open pit mine

Mogalakwena Mine is situated 30 kilometres north-west of the town of Mokopane in the Limpopo province, South Africa. The mining method is a conventional open pit, truck and shovel operation and the current pit depths vary from 60 m (Mogalakwena North) to 240 m (Sandsloot). The case study investigated here is taken from the extensive mine-to-mill study reported by Bye (2005). Following a highly successful 18-month trial period, Anglo Platinum converted its entire PPRust open pit operation – which moves 50-million tons of hard rock a year – to AEL electronic delay detonators (EDDs). The extensive trials began in 2002 and involved the major electronic detonator suppliers to the South African market.

The results from Bye (2005) indicate a small, direct unit cost benefit attributable to the introduction of EDDs through expanded patterns. The greatest benefit was seen in shovel productivity levels which resulted from better quality muck piles. When EDDs were introduced in March 2002 there was an immediate and clear improvement in loading rates. Subsequently the blast powder factor was reduced (patterns expanded) during May to December 2002. Despite this decrease in powder factor the loading rates were maintained well above the target of 3,200 t/hr. Average loading rates of up to 3,500 t/hr were recorded with instantaneous rates going up to 4,800 t/hr. A clear correlation between loading rate and pit production was visible. The EDDs afforded greater timing flexibility and repeatability.

In a subsequent phase of the project lasting from January 2003 to June 2003 the effect of increasing the powder factor on the crushing and milling rates was studied. As shown in Figure 1, the powder factor ranged from 1.3 to 1.9 and the milling rates increased from around 140 tons/hr to 175 tons/hr, a 17 % increase (Little 2006). Similar changes are demonstrated by Workman and Eloranto

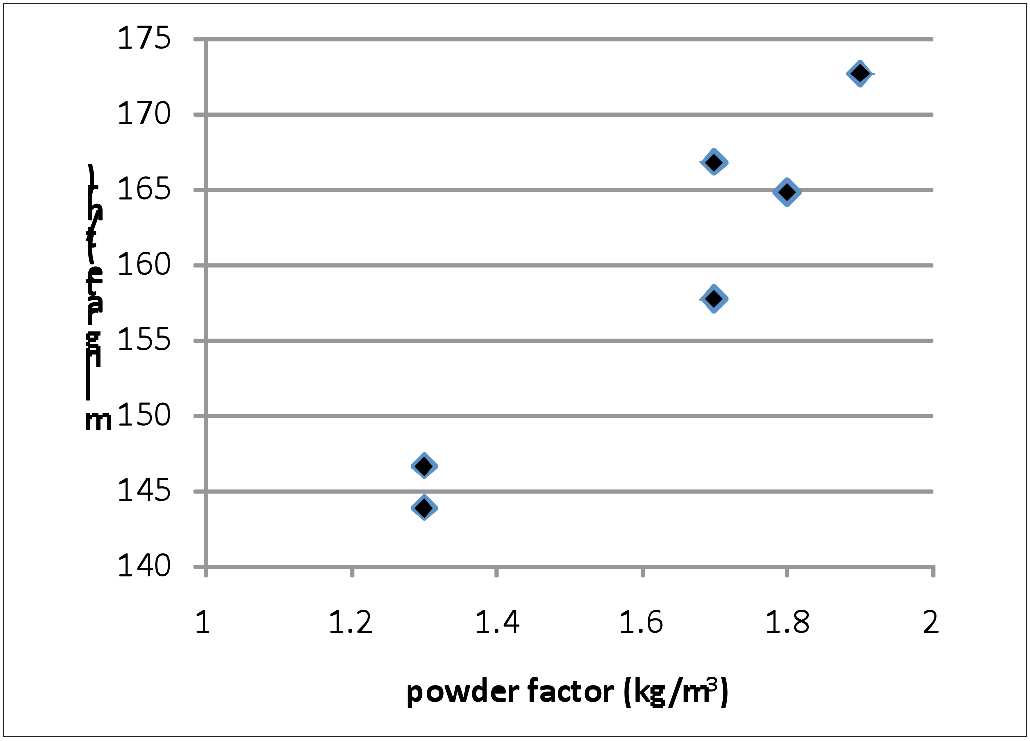

Figure 1. Increase in mill throughput attributed to higher mine-to-mill powder factors and the blast control EDDs provided (Bye 2005).

(2003) and others. In this study, we consider the effect of the change from shock tube to electronic detonators as well as the increased powder factor.

3.2.1 Methodology

The carbon benefit model was applied in the quantification of energies used throughout the mine-to-mill value chain. It must be noted that the fragmentation results improved from 80 % passing 35 cm to 80 % passing 25 cm. The rock structure at the mine is complex (Bye 2005) and all of the model results are calculated with a typical work index for the pyroxenite platreef that improved from 19.7 kWh/ton to 15.1 kWh/ton. The equipment used on the mine at the time was obtained from the AngoPlatinum annual report (Angloplatinum 2006) and only one machine was selected for each category for the purposes of this model. The costs and fuel consumptions are therefore assumptions, but are sufficiently accurate to allow us to study the effect of the changes on the carbon footprint. More detail will be added later. The main differences between this mine and the previous quarry study are the much larger size of equipment used and the use of electric drills and shovels at this very large mine.

3.2.2 Benefits summary

Table 3 shows the results of the calculations and indicates an annual saving of 86,580 l of diesel from hauling improvements and 20,989 MWh/annum from electrical energy use. The total carbon footprint savings were 39,170 tons per annum (a 18.8 % reduction). The monetary value associated with the equivalent electrical and fuel reductions is approximately $4.4 million per annum, which is a 17 % improvement. Note that these numbers are significantly dependent on the cost assumptions and may not reflect the real costs at the mine. The main issue here is the additional drilling required to increase the powder factor so significantly. There is a delicate balance between the electricity used for drilling and the electricity saved by crushing. There must be large savings in the crusher, which can only arise from an increased mass of the size fraction that circumvents the crusher without being acted upon.

Table 3. Quantification of benefits at Mogalakwena based on Bye (2005).

			Values / Description			
Category	**Item**	**Units/Description**	**base case**	**Improved**	**Change**	**%Change**
Bench Geometry, Geology and Production	Annual production (Ore &Waste)	tons	50000000	50000000		
	Monthly production (Ore)	tons	425000	425000		
	Total Holes drilled annually		15617	29579		
	Average explosives used per month	tons	23138.2	43823.3	20685	89%
	Bench Height	m	15.0	15.0	0	
	Rock Type	Platreef	Platreef	Platreef	0	
	Ore/Waste	Ore/waste	Ore/waste	Ore/waste	0	
	Rock Density	tons/m^3	2.9	2.9	0	
	Rock Index (Wi)	kWh/ton	24.22	19.7	0	
	Rock Mass Rating		Hard rock	Hard rock	0	
	Hole Depth	m	15	15	0	
Blast Design Input Parameters	Explosives type		emulsion	emulsion	0	
	Explosives Density	g/cc	1.3	1.3	0	
	Initiation system		S/Tube	EDD's		
	Burden	m	8	5.8	0	
	Spacing	m	9.2	6.7	0	
	Hole diameter	mm	311	311	0	
	Inter-hole timing	ms	17	41		
	Inter-row timing	ms	42	70		
	Stemming length	m	5	5		
	Overall Powder factor	kg/m^3	1.00	1.90		
Drilling	Drilling Rate	m/hr	15	15		
	Electricity Consumption	kWh	16310594.7	30891913.8		89%
Fragmentation	P50 Size (Ore)	cm	14.0	7.2	-6.8	-49%
	P80 Size (Ore)	cm	38.0	18	-20.0	-53%
	Top Size (Ore)	cm	110.0	60	-50.0	-45%
Loading	Bucket size	m^3	26.00	26.00	-	-
	Loading rate	tons/Opr hrs	3300	3800	500	15%
	electricity consumption	kW	1680	1680		
	electricity	kWh/annum	25454545	22105263	-3349282	-13%
Hauling	Haul Truck Capacity	tons	136.00	136.00	0	
	Haul fleet production rate	tons/hr	3300	3500	200	6%
	Haul fleet production rate (Ore)	tons/hr	3300	3500	200	6%
	Haul fleet production rate (waste)	tons/hr	3300	3500	200	6%
	Hauling Fuel Consumption	l/hr	100	100		
Beneficiation	Primary Crusher Production Rate	tons/hr	148.00	170	22.00	15%
	Primary Crusher feed Size	cm	38.00	18	-20.00	-53%
	Primary Crusher Product Size	cm	10.20	10.20	0.00	0%
	Secondary Crusher Product Size	cm	1.9100	1.91	0.00	0%
	Grinding / Final Product size	cm	0.0053	0.0053	0.00	0%
	Blasting Work Input	kWh/ton	0.2700	0.24	-0.03	-11%
	Primary Crusher Work Input	kWh/ton	0.3655	0.116	-0.25	-68%
	Secondary Crusher Work Input	kWh/ton	0.9941	0.6157	-0.38	-38%
	Grinding Work Input	kWh/ton	31.516	25.635	-5.88	-19%
Carbon Rating	Explosives	kgCO2-e/kg	0.25	0.25		
	Diesel	kgCO2-e/l	2.5	2.5		
	Electricity	kgCO2-e/kWh	1.08	1.08		
Energies	Total Explosives	kg/annum	277658623	525879429	248220807	89%
	Total Fuel used	litres/annum	1515152	1428571	-86580	-6%
	Total Electricity used	kWh/annum	209431865	170063982	-39367882	-18.8%
Carbon FootPrint	Explosives	kgCO2-e/annum	69414656	131469857	62055202	89%
	Fuel	kgCO2-e/annum	3787879	3571429	-216450	-6%
	Electricity	kgCO2-e/annum	226186414	183669101	-42517313	-19%
	Total	**kgCO2-e/annum**	**525575362**	**502379488**	**-23195874**	**-4%**
Annual cost	Drilling	$	-	-	-	-
	Blasting	$	-	-	-	-
	Loading	$	$2 570 909.09	$2 232 631.58	-$338 277.51	-13%
	Hauling	$	$1 704 545.45	$1 607 142.86	-$97 402.60	-6%
	Beneficiation	$	$21 152 618.32	$17 176 462.23	-$3 976 156.09	-19%
	Carbon footprint (Carbon tax)	$				
	Total Cost	$	**$25 428 072.86**	**$21 016 236.67**	**-$4 411 836.19**	**-17%**

Table 4. Quantification of carbon footprint at a cement mine.

			Values / Description			
Category	**Item**	**Units/Discription**	**S/Tube**	**EDD's**	**Change**	**%Change**
Bench Geometry, Geology and Production	Annual production	tons	4100000	4100000		
	Total Holes drilled annualy		8874	8874		
	Average explosives used per month	tons	906.6	906.6	0	
	Bench Height	m	10.0	10.0	0	
	Rock Type	Limestone	Limestone	Limestone	0	
	Rock Density	tons/m^3	2.1	2.1	0	
	Rock Index (Wi)	kWh/ton	10.8	13.6	0	
	Hole Depth	m	10	10	0	
Blast Design Input Parameters	Explosives type	doped emulsion	S135	S135	0	
	Explosives Density	g/cc	1.25	1.25	0	
	Burden	m	4	4	0	
	Spacing	m	5.5	5.5	0	
	Hole diameter	mm	102	102	0	
	Inter-hole timing	ms	17	17		
	Inter-row timing	ms	42	25		
	Stemming length	m	3	3		
	Powder factor	kg/m^3	0.33	0.33		
Drilling	Drilling Rate	m/hr	15	15		
	Fuel Consumption	l/hr	5.5	5.5		
Fragmentation	P20 Size	cm	3.396	4.065	0.7	20%
	P50 Size	cm	14.597	15.996	1.4	10%
	P80 Size	cm	31.369	37.581	6.2	20%
	Top Size	cm	61.534	83.336	21.8	35%
Loading	Bucket size	m^3	11.00	11.00	-	-
	Loading rate	tons/hr	2190	1877	-313	-14%
	Loading Fuel Consumption rate	l/hr	40	40		
Hauling	Haul Truck Capacity	tons	55.00	55.00	0	
	Haul fleet production rate	tons/hr	2190	1877	-313	-14%
	Hauling Fuel Consumption	l/hr	50	50	0	0%
Beneficiation	Primary Crusher Production Rate	tons/hr	148.00	150	2.00	1%
	Primary Crusher feed Size	cm	31.37	37.581	6.21	20%
	Primary Crusher Product Size	cm	10.20	10.20	0.00	0%
	Secondary Crusher Product Size	cm	1.9100	1.9100	0.00	0%
	Grinding / Final Product size	cm	0.0053	0.0053	0.00	0%
	Blasting Work Input	kWh/ton	0.2400	0.24	0.00	0%
	Primary Crusher Work Input	kWh/ton	0.1453	0.204	0.06	40%
	Secondary Crusher Work Input	kWh/ton	0.4433	0.559	0.12	26%
	Grinding Work Input	kWh/ton	14.05	17.707	3.65	26%
Carbon Rating	Explosives	kgCO2-e/kg	0.25	0.25		0%
	Diesel	kgCO2-e/l	2.5	2.5		0%
	Electricity	kgCO2-e/kWh	1.08	1.08		0%
Energies	Total Explosives	kg/annum	10879403	10879403	0	0%
	Total Fuel used	litres/annum	201033	229130	28097	14%
	Total Electricity used	kWh/annum	60032657	74716532	14683875	24%
Carbon Foot Print	Explosives	kgCO2-e/annum	2719851	2719851	0	0%
	Electricity	kgCO2-e/annum	64835269	80693855	15858585	24%
	Total	**kgCO2-e/annum**	**68057702**	**83986531**	**15928828**	**23.405%**
Annual cost	Drilling	$	-	-	-	-
	Blasting	$	-	-	-	-
	Loading	$	$106 979.78	$124 819.24	$17 839.46	17%
	Hauling	$	$133 724.72	$156 024.05	$22 299.33	17%
	Beneficiation	$	$6 063 298.34	$7 546 369.75	$1 483 071.41	24%
	Carbon footprint (Carbon tax)	$				
	Total Cost	$	**$6 304 002.84**	**$7 827 213.04**	**$1 523 210.20**	**24%**

3.3 Cement mine fines project

The cement mine used in this ongoing case study is situated in the Northern Cape, South Africa. This is a lime producing mine with an installed burnt lime capacity of 1.0 million tons per annum. Four rotary kilns are in operation. Major revenue losses as a result of fines was experienced at the mine and so a fines reduction project was then initiated which focused on optimising blast design to ensure lower fines generation. This was followed by the introduction of electronic delay detonators introduced in December 2009. Fines were defined as particles less than 8 mm and oversize being particles bigger than 700 mm. Therefore, the project focused on fines reduction without neglecting the oversize.

3.3.1 Methodology

It is important to note in the cement mine case study the fragmentation size was increased from 80 % passing 31.37 cm to a product size of 80 % passing 37.58 cm. Using the same logic applied in the two case studies discussed earlier the energy usage in the processing of ore will be increased. Limestone has a work index of 10.8 kWh/ton. Increasing the fragmentation size by 6.2 cm will increase the work index to 13.6 kWh/ton, assuming a linear rate of 0.45 kWh/ton/cm. Obviously the exact trend of work index needs to be determined.

3.3.2 Benefits Summary

Table 4 shows that the model indicates an annual increase in of 28,097 l (14%) of diesel from loading and hauling, 8,803 MWh/annum (i.e. 26%) from electrical energy use. The total carbon footprint increased by 9,578 tons per annum (24.26% increase). The monetary value associated with the equivalent electrical and fuel increase was $929,312 per annum (25%) of total revenue losses, excluding the savings from improved haulage efficiency and reduced secondary breaking. This cost has also to be compensated by the effect of the decrease in fines on plant performance that has not yet been quantified. Also, in their discussion of the less fines project Segarra et al. (2005) showed a decrease fines as well as a slight decrease in the 80% passing. The change in powder factor appears to be the main parameter governing fragmentation, overcoming other design and execution factors, including the use of electronic detonators. The work at this cement mine will continue to obtain a solution that has a better carbon footprint. The example is included to show that changes made for one reason may be detrimental for another and that the overall mine economics and environmental status must be assessed to decide on which option is most optimal.

4. CONCLUSIONS

The conventional mine-to-mill model typically used to demonstrate the benefits from particle size reduction through explosives is expanded to quantify the additional greenhouse gasses produced and energy changes incurred in the process. This allows the interpretation of whether the project contributes to the improvement of the environmental considerations that are vital at this stage of the global emphasis on carbon savings. In addition, the model contributes to evaluate if there is a total saving in electricity, which is vital in many countries such as South African where electricity production has reached saturation. It can be concluded that environmental conscious blast designs are not only a charity affair as previously perceived by many mining companies but are real profitable. It can be said that the introduction of EDDs in most mining operations has clearly added value and reduced operating costs by increasing productivity through improved loading rates, higher mill performance and reduced wastage. However, saving electricity in the crusher by increasing the powder factor has a much more sensitive relationship to the input costs and care must be taken to balance increased drilling with decreased crushing, especially when electric drills are used.

From the studies discussed in this paper it could be seen that not all the mines desire reduced fragmentation size, some mines require a blast design that will favour coarser fragmentation. The point that is being made is that such a fragmentation increase does result in downstream revenue losses and a significant environmental impact that is more often than not, neglected.

The gap that exists in the industry is the failure to see the overall blasting benefit from a mine-to-mill perspective and the added bonus of possible improvements to the triple bottom line. Blasting and processing are often dealt with in isolation without a link and as a result an opportunity is missed where a small upstream investment provides major returns downstream. As the way forward from this exercise continuous improvement on blast designs will be facilitated in the identified mines, measurements will be done and recorded to demonstrate actual benefits. The trends and interdependencies need to be quantified more accurately. The main objective will be to compare the theoretical predictions to the actual result in the process of developing a more reliable model.

REFERENCES

Angloplatinum 2006. www.angloplatinum.com/investors/presentations/documents/analyst_091106/analyst_091106.pdf

Bond, F. C. 1952. The Third Theory of Comminution. *Mining Engineering*, May pp 484-494.

Bond, F. C. 1961. Crushing and Grinding Calculations, Part II. *British Chemical Engineering*.

Brent, G.F. 2010. Greenhouse gas implications of explosives and blasting Rock Fragmentation by Blasting – Sanchidrián (ed). *Taylor & Francis Group*, London, ISBN 978-0-415-48296-7. Pp 673-681

Bye, A. R. 2005. Unlocking value through the application of EDDs at Anglo Platinum's, PPRust open pit operations. *First SAIMM International Seminar on Strategic versus Tactical Approaches in Mining Conference*. Johannesburg, South Africa, South African Institute of Mining and Metallurgy.

Coe, E. 2005. Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. *EPA420-F-05-001* February 2005.

Cunningham, C., Braithwaite, M. & Parker I. 2008. Vixen Detonation Codes: Energy Input for the HSBM. *Fragblast-8*, Santiago, Chile, 169- 174.

Eberhard, A., Foster, V., Briceño-Garmendia, C., Ouedraogo, F., Camos, D. & Shkaratan, M. 2008. Underpowered:The State of the Power Sector in Sub-Saharan *Africa. Africa infrastructure country diagnostic*. World Bank.

Gumede, X. 2007. Eskom unpublished report.

Letete, T., Guma, M. & Marquard, A. 2010. Information on climate change in South Africa: greenhouse gas emissions and mitigation options. *Energy Research Centre. University of Cape Town*. http://www.erc.uct.ac.za/Information/Climate%20change/Climate_change_info3-Carbon_accounting.pdf

Little, M. J. 2006. Geotechnical strategy and tactics at Anglo Platinum's PPRust open pit operation, Limpopo Province, South Africa. *Master of Science in Engineering research report. University of Witwatersrand*, Johannesburg.

Kecojevic, V., Bogunovic, D. & Komljenovic, D. 2010. Fuel Consumption, CO2 Emission and Economic Cost Under Various Operating Conditions. *The 21th Annual Meeting, Society of Mining Professors*, June 18-22, Tallinn, Estonia.

Kutz, M. 2010. Best practices for mitigating environmental damage from conventional power generation. *Environmentally Conscious Fossil Energy Production. John Wiley and Sons, 2010* - Technology & Engineering - 368 pages.

Mlamo-Ngcuka, P. 2004. Draft Energy Efficiency Strategy of the Republic of South Africa. *Department of Minerals and Energy*. http://www.info.gov.za/view/DownloadFileAction?id=70151.

Nielsen, K. & Kristiansen, J. 1996. Blasting-Crushing-Grinding: Optimisation of an Integrated Comminution System. *Proc. of FRAGBLAST 5, Fragmentation by Blasting*, Montreal, Canada, August 25-29, pp 269-277.

Pitchford, J. & Moeller, W. 2007. ED Success at a local Quarry. *Detnet internal presentation*. www.detnet.com

Richards, A. B. & Moore, A.J. 2008. Environmental Blast Simulation. *Fragblast-8*, Santiago, Chile, 271-278.

Scott, A. Michaux, S. & Onederra, I. 2010. Characterising dust generation from blasting Rock Fragmentation by Blasting – Sanchidrián (ed), *Taylor & Francis Group, London*, ISBN 978-0-415-48296-7, 663-671.

Segarra, P., Sanchidrián, J.A., Moser, P., Grasedieck, A., Smöch, B. & Pascual, J.A. 2005. Energy-controlled blasting for less fines production. *Brighton Conference Proceedings, R. Holmberg et al. European Federation of Explosives Engineers*, 535-452.

Sellers, E., Kotze, M., Wilson, L., Pienaar, A. & Szendrei, T. 2011. Community Response To Airblast And Vibration From Surface Charges. *International Society of Explosives Engineers*. San Diego. 2011G.

Spathis, A.T. 2010. A brief review of the measurement, modelling and management of vibrations produced by blasting. *Vibrations from Blasting – Spathis & Noy* (eds) © 2010 Taylor & Francis Group, London, ISBN 978-0-415-48295-0.

Sprott, D., Toppi, M., & Yeung, C. 1997. The conversion to Bulk Explosives at the Golden Pride Mine. *13th Operators Conference*. Sudbury.

Wikipedia (2009) http://en.wikipedia.org/wiki/Global_warming_potential

Workman, L. and Eloranta, J. 2003. The Effects of Blasting on Crushing and Grinding Efficiency and Energy Consumption, *Proc of the 29th Annual Conference on Explosives and Blasting Technique*, Feb., Nashville, TN.

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Life cycle assessment of a civil emulsion explosive

C. Ferreira, J.B. Ribeiro, R. Mendes & F. Freire
ADAI-LAETA, Department of Mechanical Engineering, University of Coimbra, Polo II Campus, Rua Luís Reis Santos, 3030-788 Coimbra, Portugal

ABSTRACT: Nowadays most sectors of activity are facing increasing environmental requirements and constraints due to legal impositions, and the civil explosive industry is no exception. This research presents a groundbreaking study for Portugal, with the aim of implementing the first cradle-to-grave Life Cycle Assessment for civil explosives. The results regarding the production of the emulsion explosive indicate that the major impact is associated with the manufacture of the ammonium nitrate. The ammonium nitrate contributes about 90% of the total energy required. Regarding the environmental impacts the ammonium nitrate contributes about 90% in all the impact categories. Identifying the principal cause of impacts is an approach to improve the environmental performance of the emulsion explosive manufacture and user.

1. INTRODUCTION

In the current days all economic sectors are facing increasing environmental requirements and constraints imposed by political institutions. The market of civil explosion, in their two perspectives – production and use – is no exception. Environmental management is defined as the administration pursuit of economic and social activities towards sustainable use of natural resources and minimising its environmental impact (ISO 14001, 2004). Both companies that produce and companies that use civil explosives, will benefit from performing an environmental management once they will be able to comply with legislation and also to improve their image in the market. To accomplish the proposed environmental objectives it is essential to identify and afterwards quantify the impacts associated with the manufacture and use of explosives for civil uses, and also to identify the hotspots in order that we can intervene and improve the process. One of the best suitable tools for the evaluation of those impacts is the Life Cycle Assessment (LCA) that will be presented in more detail in section 2 below.

This research presents a groundbreaking study for Portugal, with the aim of implementing the first cradle-to-grave Life Cycle Assessment for civil explosives. In fact, as far as we know, there is only a study of this kind for a civil explosive in Switzerland (Kellenberger *et al*. 2007). However, as those authors recognize, the analysis needs to be strengthened with more detailed data regarding the production and use phases. In this work that problem is almost overcome by using data from a Portuguese civil explosives company (regarding the production) and assessing the detonation emissions through the use of the

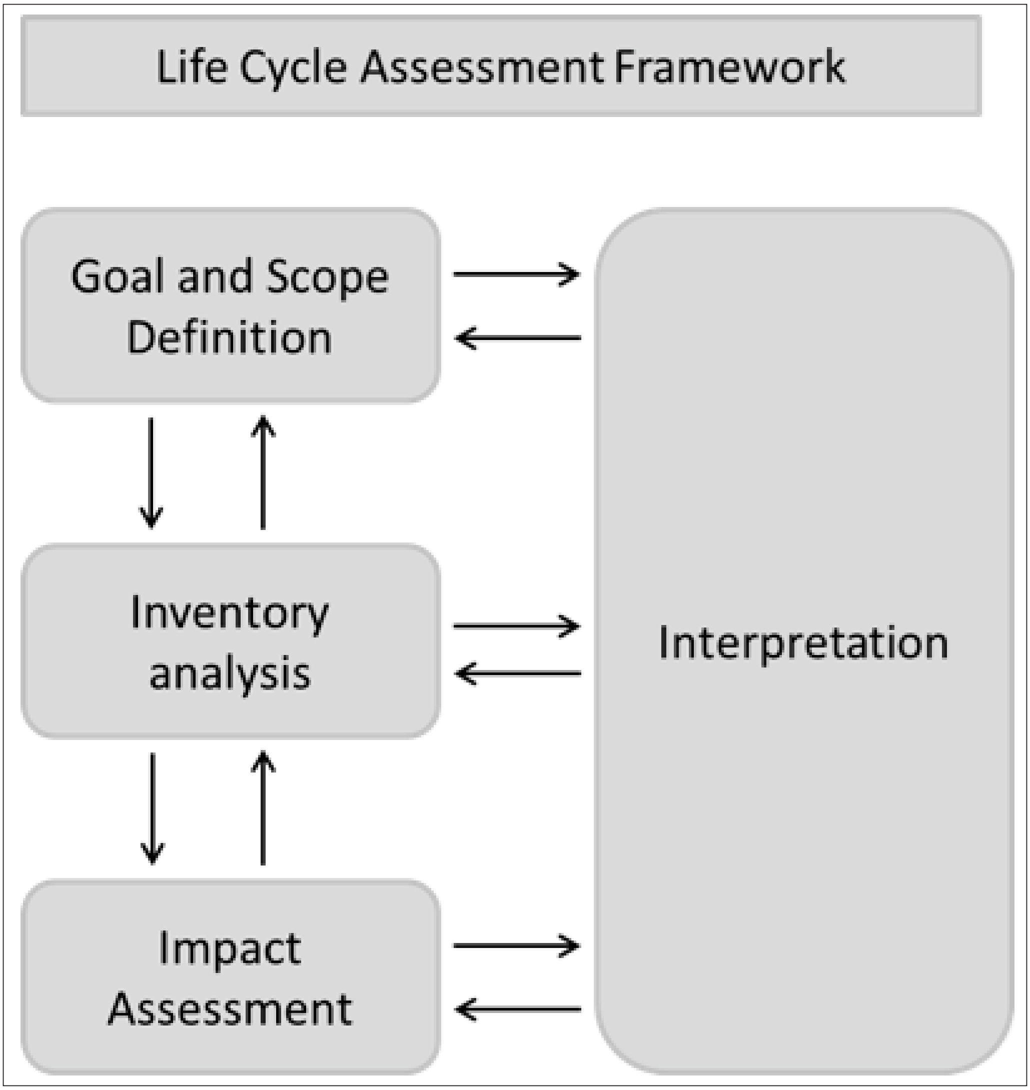

Figure 1. The LCA phases, based on ISO 14040, 2006.

thermochemical code *THOR* (Duraes *et al*. 1998).

2. METHODOLOGY AND INVENTORY

The Life Cycle Assessment is a method for quantifying the potential environmental impacts associated with full life cycle of products or services (ISO 14040, 2006), and can be a powerful tool for decision support to assess and/or compare products. The LCA consists of four phases interrelated as illustrated in Figure 1, based on the ISO 14040. In the first phase the goal of the study is defined and a description is done of the functional unit and system boundaries. In the *inventory analysis* the inputs and outputs of a system are compiled and the data processed. The potential impacts are evaluated in the *impact assessment* and then these results are *interpreted* relative to the objectives of the study defined in the goal and scope phase (Finnveden *et al*. 2000).

For this research the methods selected were the Cumulative Energy Demand (CED) – energy -; and the CML 2 Baseline 2000 (CML) – environment.

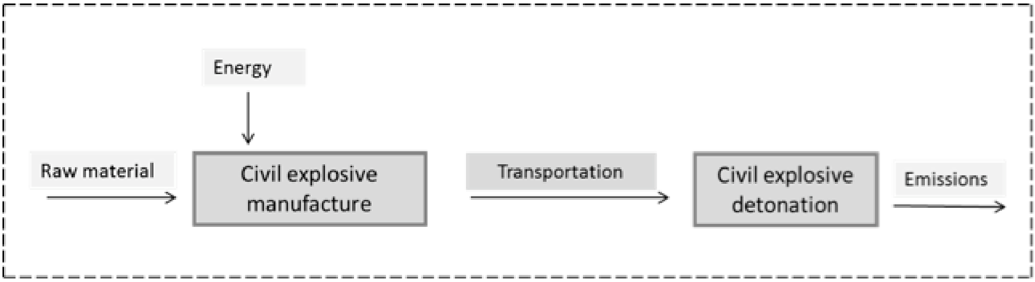

Figure 2. Cradle-to-grave boundaries of the emulsion explosive model.

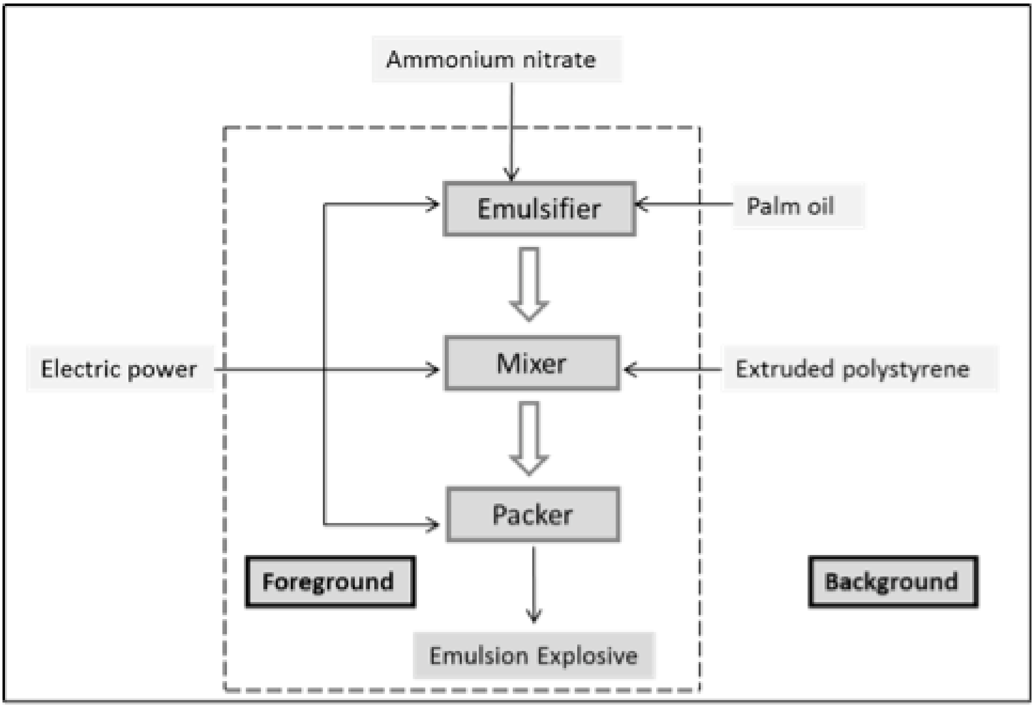

Figure 3. System boundaries of the emulsion explosive manufacture.

2.1 Emulsion explosive model

The model developed in this study is intended for the production and the use of an emulsion explosive, since it is expected that this kind of civil explosive will dominate the market in a few years time (Kellenberger *et al*. 2007). The boundaries of the model are delimited from the raw material extraction until the final product use, being a cradle-to-grave LCA study. The model also considers the transportation of the product to its final destination, considering that the transported product is used immediately. The functional unit was set to 1 kg of TNT equivalent (kg TNTeq.), corresponding to, approximately, 4.184 MJ of energy content. The system boundaries of the developed model are represented in Figure 2.

Figure 3 represents the flow-sheet for the manufacture of the emulsion explosive. The components used in the preparation of the emulsion are, essentially: the aqueous solution of ammonium nitrate, oil palm, emulsification agents and the sensitized agent (expanded polystyrene). The manufacture process comprises the emulsification, mixing and packaging which are processes distinct but sequential so in this study they were modeled as a single process.

Table 1. Data for the emulsion explosive manufacture process. All data are per functional unit.

Components	**Amount Assumed (kg/kg TNTeq)**
Ammonium Nitrate	0.88
Palm Oil	0.07
XPS	0.004
Water	0.156
Total	1.11
Consumption	**Amount (KWh/kg TNTeq.)**
Electricity	0.089

Table 2. Emissions resulting from the emulsion explosive detonation. All data are per functional unit.

Emissions from blasting	**Amount (Kg/Kg TNTeq.)**
CO_2	0.0043
H_2O	0.0376
N_2	0.0125
CO	3.28E-06
O_2	2.45E-07
H_2	2.24E-06
NH_3	6.55E-06
NO	1.62E-06
C	0.0004

2.2 Inventory

The data for the production of the civil explosive was obtained from a company in the field of the emulsion explosive production, referring to the year of 2010 and is compiled in the table 1. The electricity used was assumed to be the average Portuguese electricity mix – 17.8% coal, 0.1% oil, 29.2% natural gas, 30.1% hydro, 0.4% photovoltaic, 17.3% wind, 5,1% imported (REN). The values were converted to the function unit, knowing that 1 kg of emulsion explosive corresponds to 0.9 kg TNTeq, taking into account the emulsion explosive density and the aluminium content (Sosnin *et al*. 1998). This unit only performs the physical process, i.e., the components of the explosives are manufactured in other units and only dosed, emulsified, mixed and packaged at this company. We consider the transport of raw materials from the unit where they are produced to the emulsion explosive production place.

In the use phase the emissions resulting from detonation of the emulsion explosive were considered, as shown in Table 2. The emissions were determined by the thermochemical code THOR.

3. RESULTS

The results for the full life cycle for the civil emulsion explosive indicate that the major impacts are related to the production phase of the product. The energy and environmental impacts are dominated by the production of the emulsion explosive. For both methods the production contributes with over 97% of impacts such as are observable in Figures 4 (energy) and 5 (environment). From the results it can be concluded that the transportation of the product to the place of detonation is representing a small part of some energy and environmental impact categories. The impacts related to blasting are marginal compared with those resulting from production of the emulsion explosive, as overall emissions are emitted in minor quantities. The emissions from the detonation of the emulsion explosive may be relevant for their local or cumulative effect.

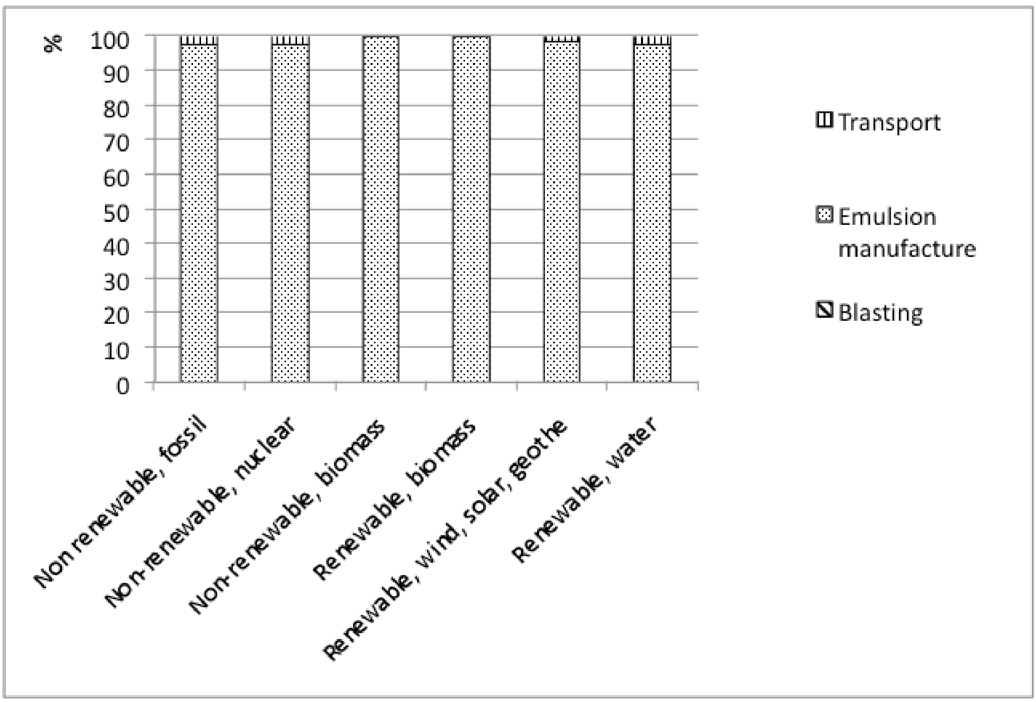

Figure 4. Energetic impacts regarding the emulsion explosive model.

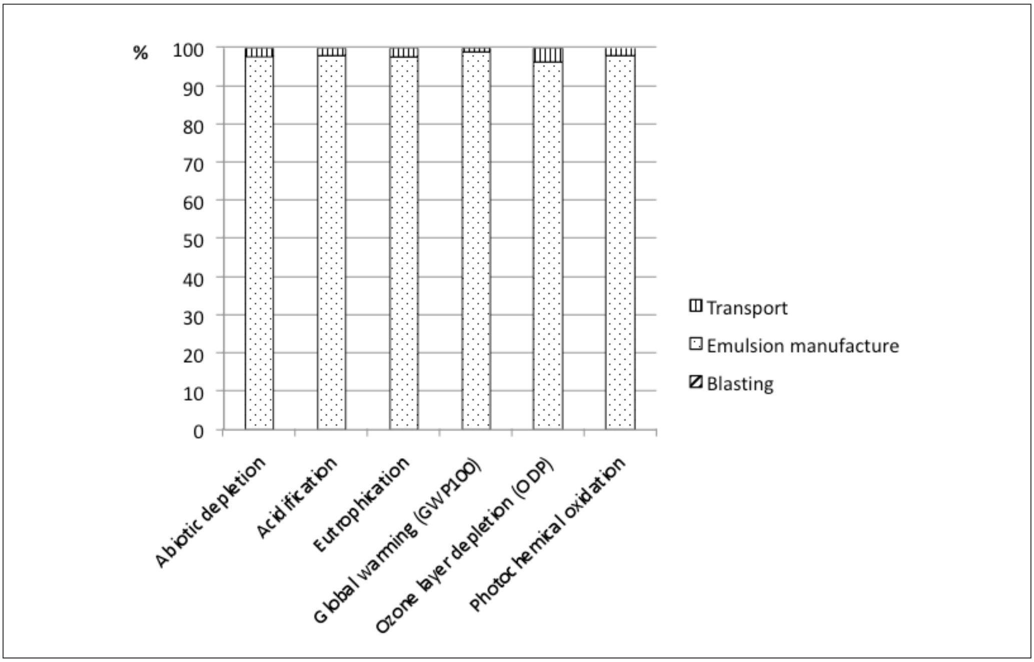

Figure 5. Environmental impacts regarding the emulsion explosive model.

Table 3. Energy required for the emulsion explosive manufacture.

Type of energy required (MJ primary)	Emulsion explosive manufacture					Transport, tank truck	Transport, semi-trailer	Equipment	Total
	Ammonium nitrate	Palm oil	Electricity	XPS	LDPE				
Fossil	50.75	0.41	0.12	0.38	2.28	1.88	0.02	0.82	56.66
Nuclear	2.53	0.15	0.59	0.02	0.24	0.03	0.0004	0.09	3.65
Biomass	0.36	4.42	0.004	0.009	0.01	0.001	1.32E-5	0.01	4.81
Wind, Solar, Geothe	0.04	0.0007	0.002	4.37E-7	1.17E-6	0.0004	3.67E-6	0.0015	0.05
Water	0.47	0.03	0.13	0.001	0.03	0.004	8.08E-5	0.03	0.69
Total	54.16	5.01	0.85	0.41	2.57	1.91	0.02	0.95	65.86

Table 4. Environmental impacts regarding the emulsion explosive manufacture.

Impact category	Unit	Total	Emulsion explosive manufacture					Transport, tank truck	Transport, semi-trailer	Equipment
			Ammonium nitrate	Palm oil	Electricity	XPS	LDPE			
Abiotic depletion	kg Sb eq	0.0277	0.025	0.0002	7.49E-05	0.0002	0.001	0.0008	3.49E-06	0.0005
Acidification	kg SO2 eq	0.023	0.022	0.0005	2.79E-05	4.82E-05	0.0002	0.0003	2.65E-06	0.0003
Eutrophication	kg PO4 eq	0.0046	0.004	0.0003	2.41E-06	4.56E-06	2.02E-05	2.54E-05	5.75E-07	5.25E-05
Global warming	kg CO2 eq	7.842	7.64	-0.07	0.01	0.015	0.067	0.12	0.0005	0.063
Ozone layer depletion	kg CFC-11 eq	3.88E-07	3.64E-07	3.07E-09	1.22E-09	1.71E-10	8.36E-12	1.73E-08	7.83E-11	2.24E-09

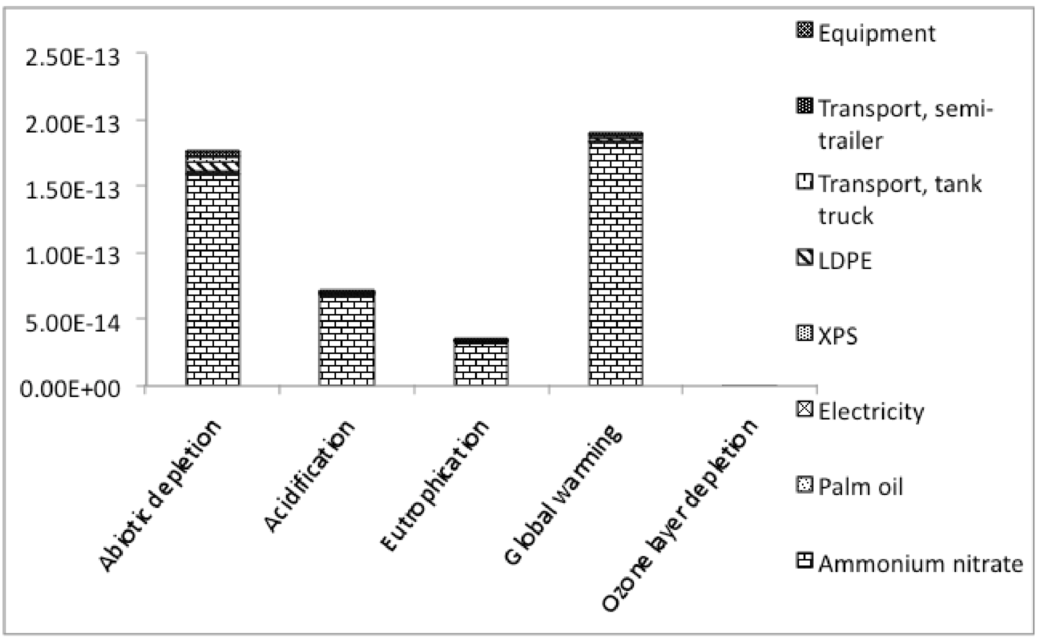

Figure 6. Normalized values for the emulsion explosive manufacture.

In order to understand the impacts on the production of the emulsion explosive it is important to identify what makes the major contribution in this process. The energy required for the emulsion explosive manufacture is indicated in Table 3. The result shows the consumption of 66 MJ for the process regarding the production of 1 kg of TNTeq. of emulsion explosive, where the fossil energy is about 86% of this total. The major consumption of energy is related with the ammonium nitrate manufacture, the principal raw material of the emulsion explosive, contributing with 89.6%.

The environmental performance regarding the production of the emulsion explosive is represented in the Table 4 of the Appendix. The major impacts, for all the impacts categories, are also due to the manufacture of the ammonium nitrate, contributing with over 90% in all impact categories. Due to the carbon sequestration the palm oil has a negative contribution to the global warming (-0.89%). The Figure 6 displays the normalized environmental impacts. It appears that the emulsion explosive manufacture has a greater impact on the global warming (40%) and the abiotic depletion (37.4%), essentially because of the ammonium nitrate manufacture.

4. CONCLUSION

From the results it was determined that the emulsion explosive manufacturing phase has the greatest impact on the overall life cycle of the emulsion explosive. The main cause of the impacts in the production phase is the utilization of ammonium nitrate, the main raw material in the emulsion explosive manufacture. The global impacts related to the detonation of the explosive civil eventually do not have much importance on the life cycle of the emulsion explosive comparative to the impacts of production. This is because the emissions from the detonation do not have a great effect to the global impact categories. However, in future, we intend to evaluate the local effects of these emissions to obtain a more reliable assessment of the impacts regarding the total life cycle of the civil explosive.

The results also allow the identification and determination of what are the aspects more significant to the environmental performance of the emulsion explosive manufacture and use.

One potential alternative to improve the process is replacing the ammonium nitrate for military energetic material, thereby avoiding the use of ammonium nitrate and valorize a residue from the military explosives.

REFERENCES

Duraes, L., Campos, J. and Portugal, A., 1998. Reaction path of energetic materials using THOR code. *In D. P. D. and J. W. F. S. C. Schmidt (eds.), Shock Compression of Condensed Matter*—1997, Woodbury, NY: American Institute of Physics.

Finnveden, G., Johansson, J., Lind, P. and Moberg, Å., 2000). Life Cycle Assessments of Energy from Solid Waste. *FOA Report, ISBN 91-7056-103-6.*

ISO 14040, 2006. Environmental management - Life cycle assessment –Principles and framework.

ISO 14001, 2004. Environmental management Standard.

Kellenberger, D., Althaus, H., Künniger, T. and Lehmann, M., 2007. Life Cycle Inventories of Building Products. *Ecoinvent report No. 7*, Dübendorf.

REN, Rede Energética Portuguesa, accessed April 2010, in www.ren.pt.

Sosnin, V.A., Smirnov, S.P. and Sakhipov, R.Kh., 1998. Evaluation of the Strength and Efficiency of the Energy Transformation of Industrial Emulsion Explosives. *Combustion, Explosion, and Shock Waves, Vol. 34, No. 5*, pp 587.589.

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Improving security in the transport of explosives by road using geolocation technology

J. Góis
LEDAP, ADAI, DEM, University of Coimbra, Portugal

D. Antunes
MAXAMPOR, SA, Portugal

P. Barbas
SEC, SA, Portugal

M. Memeteau & R. Lafiton
ComUT, Portugal

ABSTRACT: The security in the transport of explosives has particular importance to decrease the likelihood of misappropriation and theft of explosive material and devices. In Portugal the transport of explosives is mainly regulated by the Decree-law 521/71, which prescribes a police escort when more than 500 kg of class 1 explosives is handled. In 2008, responding to a European challenge on improving security in the explosives supply chain, a pilot project based on Global Positioning Systems was initiated to evaluate the performance and reliability of this technology. A GPS device monitoring the transport and a real-time alarm system operated by the driver were tested. Preliminary route and deliveries location is set-up by the fleet manager and validated by the Police authority. GPS completed by sensors, allow real-time tracking by the police and the alarm algorithm provides a complementary control of any anomaly. This new technology allows with relative moderate cost to enlarge and increase the security of transport of explosives below 500 kg. This paper describes the several tests of feasibility of this technology and the development carried out to achieve a reliable system able to reduce the risk of cargo theft and terrorist attacks.

1. INTRODUCTION

Terrorists have used trucks filled with explosives in some of the worst terrorist attacks in history. Recently in Mumbai India on 14th July a terrorist attack killed more than one hundred people, hurt hundreds of others and destroyed a federal building with a truck carrying common agricultural chemicals. Small quantities of explosives were used in Madrid on 11 March 2004 terrorist attacks. The risk of explosives falling into the hands of terrorists and the threats of terrorism attacks led the European Commission to adopt security measures for explosives in all stages of the supply chain. In April 2004 the Commission adopted Decision 2004/388/EC, which harmonizes the requisite information and procedures to be followed for the transfer of explosives between Members States. Commission calls at this time for a policy on the security of the national supply chain in order to complement existing legislation in various areas of transport security and in particular for land transport. The Explosives Security Task Force (ESTF) created by EU Commission proposed that all EX/II and EX/III vehicles carrying explosives shall be equipped with the security enhancement solutions identified below:

- Be fitted with 24 hour remote monitoring systems;
- Be capable of immobilizing the engine remotely if safe and applicable;
- Be fitted with an anti theft system;
- Be fitted with a means of communication;
- Have a recognized marking affixed to the roof of the vehicle.

The contribution of the Portuguese explosives sector to increase security in land transport started during the 2nd EU Conference on Enhancing the Security of Explosives that was held in Braga, Portugal, on 16-17 July 1997. At this time all three explosives manufacturers, encouraged by the Portuguese Association of Studies and Engineering of Explosives (AP3E) and the cooperation of the National Department of Police (DNPSP/DAE), established a partnership with the company ComUT, specialist in Transport Management Systems, with the purpose of evaluating the reliability and performance of GPS technology on transport security of explosives.

Pushed by the discussion on Enhancing the Security of Explosives, during the period of time of the Portuguese Presidency of the EU, the Portuguese Minister of National Affairs decided to support this pilot project, entitled SIGESTE (Security System and Explosives Transport Management), issuing the Ministerial dispatch nº 30106/2008 of 21 November.

2. PORTUGUESE EXPLOSIVES TRANSPORT REGULATIONS

The transport of explosives in Portugal is regulated by the following decrees-law:

- Decree law 41-A/2010 of April 29 that transpose into Portuguese law Directive 2006/90/EC of the Commission of 3 November and Directive 2008/68/EC of the European Parliament and the Council of 24 September on the Transport of Dangerous Goods;
- Decree law 521/71 of 24 November that regulates the security of processing, trade, storage and use of guns, ammunitions and explosives substances.
- Decree law 119/2010 of 27 October that introduce modification to Decree law 521/71 implementing integrated system for transport of explosives based on advanced geolocation technology.

Decree law 41-A/2010 of April 29, commonly referred as ADR, includes in Chapter 1.10 provisions relating to security with emphasis on the transport of high consequence dangerous goods, which include explosives (for transported quantities over 20 kg or 50 kg), ammonium nitrate and ammonium nitrate fertilizers (when quantities carried in tanks or IBCs are higher than 3000 kg). In addition to the suitability of all those people involved in transport, this Regulation highlights the need for developing and implementing a physical security plan, which, at least, must include:

a) Competent and qualified persons, who have proper authority, for the allocation of the responsibilities of physical protection of transport;
b) Records of dangerous goods or types of dangerous goods concerned;
c) Evaluation of current operations and security risks arising from transport, including stops required by the transport operations, the keeping of dangerous goods in vehicles, tanks and containers imposed by traffic conditions (before, during and after the journey) and the intermediate storage of dangerous goods for modal shift or other vehicle of transport, according to needs;
d) Clear statement of measures to be taken to reduce security risks, taking into account the responsibilities and functions involved, including:
    - Training activities;
    - Physical protection policies (eg: measures when an increasing threat is really and control when new employees are recruited or employees are assigned to certain position, etc);

- Operational practices (eg: choice and use of routes known, access to dangerous goods temporarily stored according to proximity to vulnerable infrastructure, etc.)
- Equipments and resources to be used to reduce security risks.

e) Effective and actual procedures to report and deal with security threats, breaches of security or security incidents;
f) Procedures for evaluation and testing of security plans and verification procedures for periodic review and updating of the plans;
g) Measures to ensure the integrity of transport information contained in the security plan, and
h) Measures to ensure that the distribution of information relating to the transport operation contained in the security plan is limited to people who have need of them.

Other requirements are included in this regulation referring to the need to install in the vehicles carrying high consequence dangerous goods, equipment or protective systems to prevent vehicle theft as well as its cargo, and taking measures to ensure continuous operation and effectiveness of protective systems, and adding the use of telemetry systems or other tracking methods or devices, which allow the monitoring of movement of high consequence dangerous goods, when suitable and when the necessary equipment is already installed in the vehicles.

Regarding decree law 521/71, the Clause 29 stipulates that the road transport of more than 500 kg of explosives must always be accompanied by an escort from security forces (GNR or PSP) responsible for:

− Monitoring security of cargo, fulfilling and enforcing the laws;
− Comply strictly to the route itinerary, justifying any modification;
− Submit to Police authority a report about fleet operations.

Decree law 119/2010 of 27 October amends the provisions in Clause 29 of Decree law 521/71, allowing the exemption of police escort for the transport of explosives by road when cargo is more than 500 kg, if the carrier makes use of geolocation electronic system, ensuring the continued monitoring of the transport and immediate trigger of alarm. This decree law was issued in result of success of the pilot project referred above and described below. A regulation about geolocation electronic system referred in this decree law will be published soon.

3. TRENDS IN MANAGEMENT AND SURVEILANCE OF TRANSPORT BY ROAD

For the industry, logistics helps to optimize distribution process through management techniques for promoting the efficiency and competiveness of enterprises. Around one third to two thirds of the expenses of enterprises' logistics costs are spent on transportation (Tseng *et al*. 2005). Land logistics is a very important link in logistics activities. The excessive usage of land transport brings many problems, such as traffic jams, pollution and traffic accidents. A revolution of transport policies and management has been carried out to improve transport efficiency and reliability in land transport.

As the increasing demand of time accuracy and decentralization of production, the need to reduce stock costs has led to the Just-In-Time (JIT) delivery principle, which involves more frequent delivery of materials at the right time and at the right place in the production process. The increasing value and hazardous of products require rapid transportation, because companies want to reduce the interest costs and risk of terrorist attacks.

E-commerce is the future trend for business operations and e-commerce uses electronic techniques instead of traditional paper works, which promotes the industries' efficiency and competiveness. With the JIT the number of trips is increased. Figure 1 and Figure 2 express the differences between the transport patterns of traditional trade and e-commerce.

To solve the difficulties caused by the impacts of increasing population and vehicle ownerships in the urban area the City Logistics concept was developed. Several techniques, such as Geographic Information System (GIS), Global Positioning System (GPS), Intelligent Transport System (ITS) and modeling have been used to optimize the city environment. Applications of ITS in transport systems are widespread. The most common techniques for logistics include GPS, GIS and advanced information systems. GPS provides the service of vehicles positioning. It could help the control centres to monitor and dispatch trucks. GIS provides the basic geographic database for the deliverers to enable them to organise their routes easier and faster. Advanced information systems provide the real-time information for both

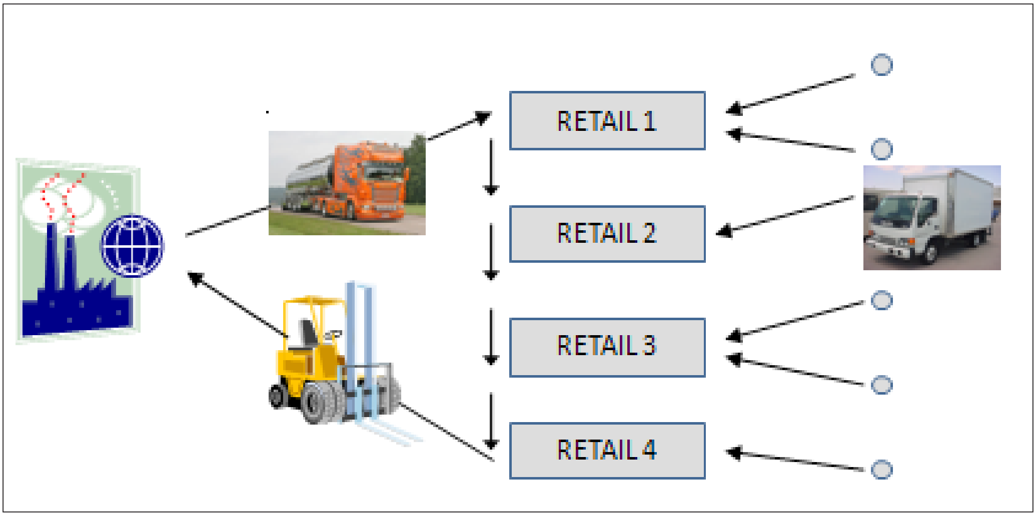

Figure 1. The transport pattern of traditional business (adapted from Tseng *et al*, 2005).

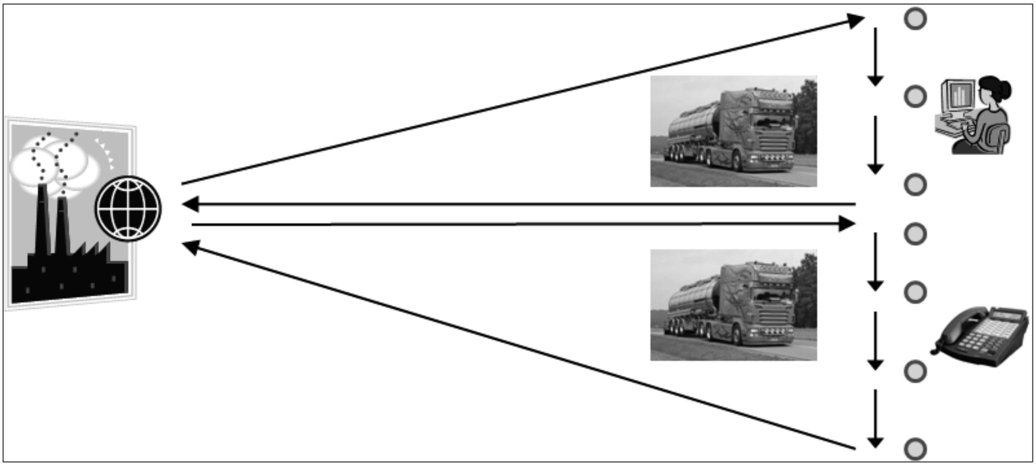
Figure 2. The transport pattern of e-commerce (adapted from Tseng *et al*, 2005).

managers and deliverymen to adjust their paths as new demands occur. The integration of GPS, GIS and advanced information systems provides a high manoeuvrability of transport systems. The benefits of the integration are better service quality, reduced unnecessary trips and increased loading rate. Moreover, it helps to reduce both transport costs and negative environmental impact.

In addition of the research in smart electronic systems that provides vehicles positioning technology providers and stakeholders in the world of global shipping propose two main solutions for securing commercial containers. The first one relies on the use of on-board systems that control the internal volume of the container by using different device sensors. These systems are able to send an alarm message to remote servers if a non-authorized door opening has been detected (Whiffen & Naylor 2005). The second solution is focused on maintaining the physical integrity of the closed container doors by means of mechanical seals. In order to overcome these problems, a new class of electronic seals based on Radio Frequency Identification Device (RFID) technology has been developed (Yoong *et al*. 2007). The basic idea is to add new security features with respect to standard. The European Commission has considered raising the need for safety in supply chains and has started the analysis of the problem through its scientific and technology reference center, the Joint Research Centre (JRC). The JRC has been focusing its research on the development of container sealing systems based on the use of passive and active RFID technologies (Rizzo *et al*. 2011). The main security features studied for the sealing system at JRC are:

- Possibility to check the proper seal closure by using an internal passive RFID system, and to save operator identity and time of closure in the internal memory;
- Possibility to record every authorized and anauthorized operation made on the seal, along with time and date;
- Possibility to check the seal's status, by remote interrogation of the electronic card memory (2.4 GHz-433 MHz active RFID communication protocol).

The results of this research until now show that at full power the communication between the system components becomes active and efficient at a mean distance of 21.9 m. Dynamic reading trials are needed to define the effective operating distance between the seals and the reading system when transponders are moving with respect to the reader.

This will be a future investigation at the JRC. Another issue in the system performance is the possible interference due to the presence of undesired medium, such as water or metallic materials. The final purpose of this research is to produce a low cost seal closure that makes it highly suitable for large scale use on commercial containers (Rizzo *et al*. 2011).

Communication is an essential feature when dealing with security through telematic devices. Encryption, improved coverage and better protection from jamming can be achieved by alternative communication protocol and infrastructures. This can be achieved by using protocols such as TETRA, TETRAPOL (Terrestrial Trunked Radio) or satellite communications.

4. PILOT PROJECT OF EXPLOSIVES TRANSPORT USING GEOLOCATION SYSTEMS

Within the framework established by the Dispatch nº 30106/2008 of 21 November entitled SIGESTE, the three Portuguese explosives manufacturers with the cooperation of the National Department of Police (DNPSP/DAE) and the technical support of ComUT, a company specializing in Transport Management Systems, built a pilot project with the purpose of evaluating the technical feasibility of the use of telematics and other well known ICT (Information and Communications Technology) systems for transport control and security of cargo.

During the pilot project 6 fully equipped trucks, 3 fleet supervisors, 18 drivers and 25 authority agents were involved.

The vehicles are equipped with an Automated Vehicle Location system (AVL) with some specific characteristics due to the environment and the context in which they will operate. This AVL unit is connected to several sensors, which provide the status of the vehicle. The information collected is treated locally and sent to a server through a proprietary protocol communication using a General Packet Radio Service (GPRS) as the main channel. Different protocol communications can be used as backup (TETRA or INMARSAT are both possibilities). Short Message Service (SMS) is also used when GPRS coverage is available. All communications are encrypted and handled by a Virtual Private Network (VPN) to avoid possible external interference. Additionally, the driver is also equipped with a mobile GPS device that allows him to warn the security center when he is not in the truck. Figure 3 shows the location and mobile communication terminal for fleet management security used by the drivers.

Globally, 3 sources of information are available to the system, indicated here with the main details delivered by the system:

− Telemetry
- Ignition
- Cargo door
- Driver door
- Passenger door
- Panic button
- Etc…

− Geospatial information
- Time/Delay
- Speed
- Position
- Heading
- Inside/Outside planned itinerary
- Inside/Outside authorized delivery zone.

− Driver information (information action, reaction to request or lack of it)

Figure 3. Equipment used for driver interaction with fleet supervisors.

- Start/end of route
- Driver identification
- Delivery warning
- Restart
- Stop/Rest.

This information is sent in real time to the server and worked out by a finite-state machine algorithm that computes the level of risk identified and associated to the different states of the system (Figure 4).

Five levels of risk are considered so far, however the system can easily be adapted to handle a different number. Those levels are:

1. Low
2. Moderate
3. Medium
4. High
5. Confirmed assault.

For example:

- Opening of the cargo door inside the itinerary with previous warning is considered as a level 2;
- Leaving the planned itinerary without warning is considered as a level 4.

Previous planning of itinerary has to be done on a dedicated web interface by operational people (usually the traffic manager of the transportation company). This interface, which is based on GoogleMaps Enterprise™ allows for use of template and ortho-photography to facilitate the introduction of itinerary and delivery areas. Figure 5 shows the web based interface for planning itinerary and Figure 6 is an example of delivery area definition.

The itinerary is planned in advance but can easily be modified during the time of delivery, if any change occurs.This part of the interface is only used to program the itinerary. The monitoring interface (Figure 7) is only visible by the competent authorities in order to monitor the operation in real-time. In order to not overload the operator, trucks are only monitored when transporting explosives.

A special emphasis has been put on offering a simple but yet powerful interface that allows quick decision making regarding the current and previous status of the vehicle as well in giving at a glance all necessary information to take quickly the best decision possible in case of emergency.

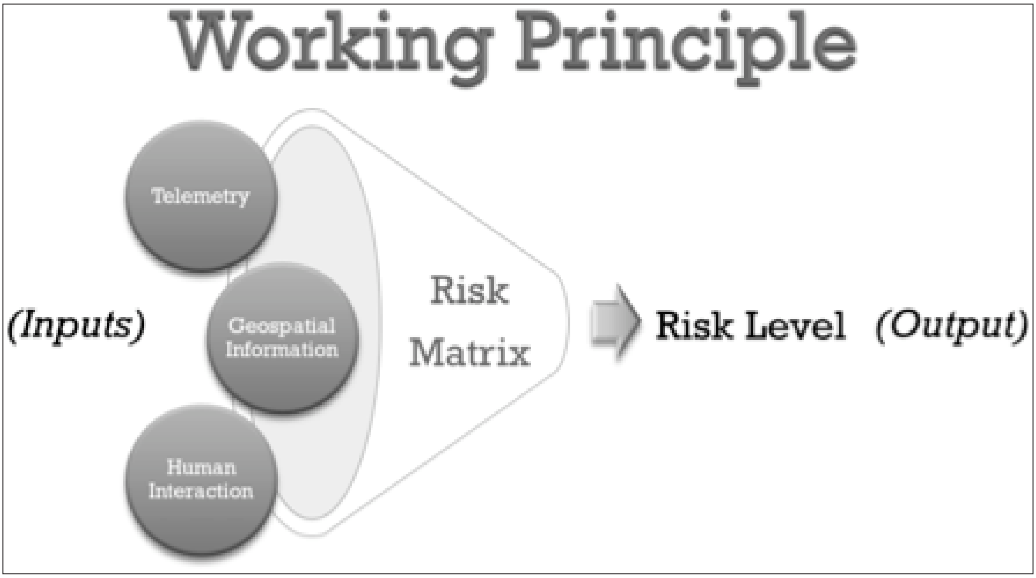

Figure 4. Working principle for identification of the level of risk.

Figure 5. Web based interface for planning itinerary.

For analysis purposes, it is possible to access the history of a particular delivery and analyse what happened (either from the point of view of the system or from the operator). Figure 8 shows an example of a delivery report. This feature was a vital aid to help to understand and improve potential flaws of the system.

During the pilot phase, several tests were conducted and areas of improvements were identified.

Figure 6. Example of delivery area definition (thick line).

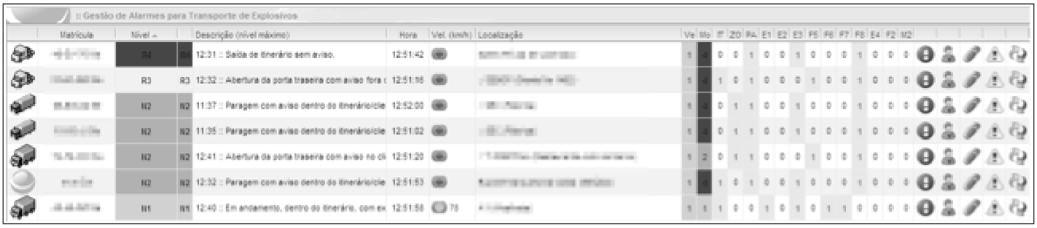

Figure 7. Web based monitoring interface.

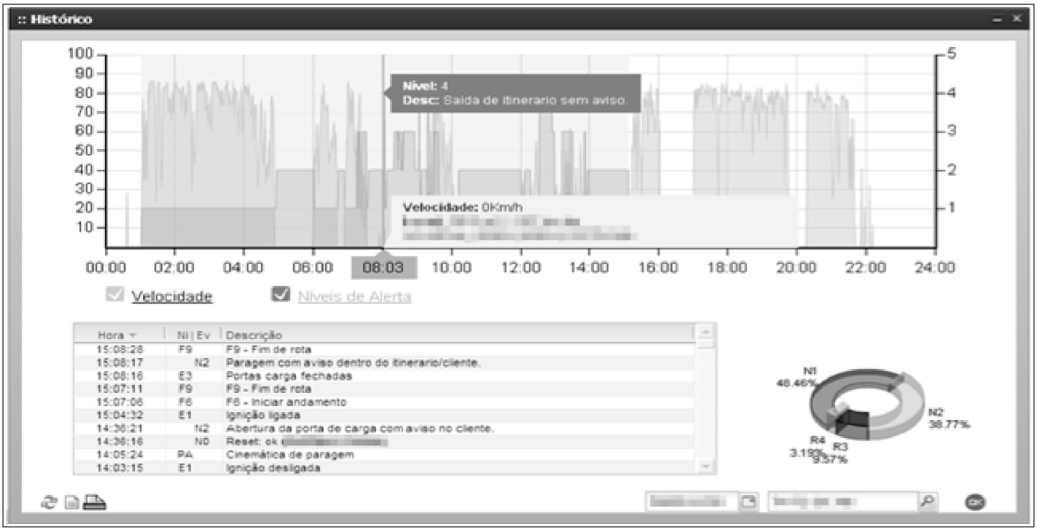

Figure 8. Report to perform further analysis.

For analysis purposes, it is possible to access the history of a particular delivery and analyse what happened (either from the point of view of the system or from the operator). Figure 8 shows an example of a delivery report. This feature was a vital aid to help to understand and improve potential flaws of the system.

During the pilot phase, several tests were conducted and areas of improvements were identified.

Analysis on the last 22 consecutive days results for 2 SEC´s trucks, is consistent with last two years trends and can be described as follows:

- On/Off procedure – This feature allows for drivers and security central operator to get the truck into the system once the delivery is starting. The driver tends to be confused about the exact moment when he should proceed, therefore causing false alarms. This is especially true, because the beginning of a journey is often a time where a lot of procedures have to be fulfilled (paperwork from leaving the factory, security check, etc.) This feature has to be simplified to be less error prone.
- Itinerary control – This was considered one of the most critical features of the project. Overall, this was judged more than adequate since only less than 0,1 % of the trucks were found outside the itinerary (less than 15 minutes in a total of 345 driving hours). However, possible improvements must be done on the way the itinerary is given to the driver (no visual interface was available at the start of the project). This is especially sensitive for new itinerary and/or new drivers.
- Delivery area – Almost same as above but concerning the delivery area. Only 2 faults were recorded. These situations were identified. They are probably related with the way the areas were defined. Up to date ortho-photos have to be available for a precise definition. A procedure to allow corrections on-the-fly and validation by the authority

would be a plus.

- Stop/Go procedure – The drivers have limited time to communicate each time they stop or start the truck. This feature was also judged prone to error, either due to delay in communication, either due to operational reason. The lack of GPRS coverage in certain delivery areas was found to be responsible for delays in messages, inducing the current algorithm in default. A proposal of improvement would be to allow the AVL device to take some decision 'locally' (useful in case of jamming or lack of communication for example) to avoid or limit this kind of behavior. This is also clearly linked to the last point.
- Driver off-truck device – Probably the least satisfactory point of the whole pilot. Mobile units were found lacking autonomy and prone to report bad GPS positions. 'Dead man' function should also be seen as an additional security feature. Better devices with improved accuracy and better battery life are currently being evaluated.
- GPS/GSM coverage (Global System for Mobile communications) – This is an important point of the whole system. Global coverage was considered extremely satisfactory. Nevertheless, as explosive delivery points are generally off-track and quarries design are usually not 'coverage friendly', it will still be possible to reach 100% coverage by considering local area limitations. Some of the communications are buffered on the AVL side (this means that delay is sometimes not perceived directly by the operator and some tolerances are built into the system), however statistical evidences show that GSM/GPRS coverage is insufficient 2% to 3% of the time. TETRA or INMARSAT are viable alternative as main or backup communication channel.

5. CONCLUSIONS

In a changing environment the risk of cargo theft and a terrorist attack pushes stakeholders in shipping, technology providers and regulators to collaborate in order to develop practical and effective systems able to respond to these threats. Industry needs to be proactive and involved in the regulation and development of new technologies addressed to security of transport of explosives.

A pilot project, entitled SIGESTE System (Explosives Safety and Transport Management), approved by the issuance of Ministerial Order nº. 30106/2008 of November 21 joined the three Portuguese manufacturing explosives companies, the National Department of Police (DNPSP/DAE) and a company specializing in Transport Management Systems (ComUT) with the purpose of evaluating the technical feasibility of the use of telematics and other well known ICT (Information and Communications Technology) on transport control and security of cargo.

Among the six features tested during the pilot project the results concerning itinerary control and delivery area have achieved high levels of efficiency. However, improvement must be done on the method as the itinerary is built and given to the driver. On/Off procedure must be revised in order to avoid false alarms. Drivers should receive specific training to avoid human errors. Communications with mobile units, operated by the driver when outside the truck, were not successful. Devices with better accuracy and higher autonomy should be tested in future. Today´s GPS/GSM coverage is considered satisfactory. With previous knowledge of delivery point limitations it is possible to guarantee full coverage. Nevertheless as coverage is a fundamental point of the whole system it's important to consider more robust communication alternatives to GPS/GSM as TETRA or INMARSAT. The capture of images from inside the cabin of trucks is also under consideration for future developments.

Despite the minor shortcomings found, the geolocation technology coupled with alarm message from driver off-truck device and others remote controls as door opening and engine allow with relative reasonable cost to enlarge security features to explosives transportation under 500 kg, increase security efficiency and make police escort dispensable for cargos over 500 kg.

In future, standards are not only needed for safety but should also be used to ensure security. To favour a reasonable cost for the implementation of systems to facilitate communication between police authority, driver and operator of transportation company efforts should be put on the harmonization of security services. Both factors will allow to enlarge security in transport of other dangerous goods.

6. ACKNOWLEDGEMENTS

We wish to thank people of the National Department of Police (DNPSP/DAE) for their involvement in this pilot project.

REFERENCES

Rizzo, F., Barboni, M., Faggion, L., Azzalian, G. and Sironi M., 2011. Improved security for commercial container transports using an innovative active RFID system. *Journal of Network and Computer Applications,* 34, pp. 845 – 852.

Tseng, Y., Yue, W. L. and Taylor, M., 2005. The role of transportation in logistics chain. *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 5, pp. 1657 – 1672.

Whiffen, J. and Naylor, M., 2005. Acoustic signal processing techniques for container security. *IEE Seminar on signal processing solutions for homeland security,* p. 7.

Yoong, W., Chung, S., Kim, H. and Lee, S., 2007. Implementation of a 433 MHz active RFID system for U-port. *Proceedings of the ninth international conference on advanced communication technology,* Vol. 1, 106-9.

Lisbon Conference Proceedings 2011, R. Holmberg et al
©2011 European Federation of Explosives Engineers, ISBN 978-0-9550290-3-5

Explosives leftovers in application sites

F. Ramalho & R. Faritas
Departamento de Armas e Explosivos, Direcção Nacional da Polícia de Segurança Pública, Portugal

ABSTRACT: The explosive products from their manufacture to the final user undergo a long course, passing through many hands. It is a long chain, in which usually the final users are admittedly the weakest link in terms of security.

In this paper, we will focus especially on the explosive products leftovers that remain on site. This includes those which for whatever reason failed to detonate, and therefore are likely to be encountered in debris removal.

1. INTRODUCTION

We presently live in an increasingly global world in which interactions between individuals, organizations and states grow. In this context, we cannot forget that the actions or omissions committed by one frequently have consequences on others.

The problem here approached, particularly the remnants of explosive products at the application site, is not at all a novelty in this sector, i.e. something that is transverse to the local and / or national field. On the other hand, this is a recurring situation that, through globalization and the growing terrorist threat, now becomes an issue of general scope.

As such, more crucial than ever, we should make every effort, and consequently take the necessary and proportionate steps in order to suppress the problem or at least minimize as possible the adverse effects.

Explicitly, this is an issue where, due to several reasons, we are faced with the carelessness of some users of explosives. Remains of explosives which have not been removed to the respective storage places are commonly found in the application sites, endangering the security of goods and people, thereby breaking the law. However, this is a legal obligation that falls on the final user. It is difficult to verify if the user did obey the law for it would be easy for the user, with malicious intentions, to circumvent these measures, unless by chance, it was proved feasible to carry out, permanently, an effective monitoring of each site. However, this does not appear feasible due to its expense (would be necessary a huge logistic and human complex). On the other hand, it is also not technically possible to accurately quantify, before or after, the quantity of explosives involved in a certain blasting operation.

Finally, we must be aware that the explosive products which were supposed to be used in a given site and were not, left their legitimate circuit and there is no longer any control over them, since they supposedly no longer exist. These 'resurrected' explosives, can then feed a black market without any rules and, eventually, if they reach the hands of terrorists, may send innocent people to their deaths.

2. SPECIFICITIES

It is not possible, perhaps not even desirable, to license and install a storage place for each application site where explosives are used, unless they are portable, secure and absolutely inviolable.

Still, this would represent a huge increase in storage places for explosives, with the inevitable consequences and costs that they represent. As a result, there are leftovers, sometimes inevitable, as result of unforeseeable circumstances (incorrect calculations, equipment malfunction, misfired explosives cartridges, etc.), sometimes this is because they are left intentionally to reduce shipping costs, to deal with any secondary fragmentations or, what is a more serious and real concern, to serve a black market in illegal and unknown uses, certainly illegitimate and dangerous.

3. FACTS

The facts speak for themselves. Unfortunately, too often, there are deviations of explosives from application sites (construction sites, quarries, mines etc.), which in some cases are subsequently recovered by police, sometimes at the employment location, and certainly more disturbing, already in the hands of others. In any case, the frequent seizures of these products show how often this phenomenon occurs and the need for preventive measures. It appears highly advisable to reflect on the prevention of this situation from happening.

4. LEGAL HARMONISATION

Although, in terms of different countries, there are various legal provisions on this matter, there is no regulatory framework at an international level – with the exception of the Directive 2008/43/EC of April 4, 2008, which establishes a system for the identification and traceability of explosives for civil use.

Although already transposed by MS in the EU, this directive has not been implemented yet. It is expected that its implementation only takes effect in 2015, so in practice, its applicability has no achievement as of yet.

Naturally, the implementation of traceability of explosive products, by itself, is not expected to completely solve the subject here approached. However, this constitutes a very useful tool in the future which should be complemented with other measures, given that the creation of any normative regulations should be in the perspective of global application and not, as is the case today, by the existence of loose legal provisions that not only contradict the uniformity that this subject craves, but also, and worse, it often appears that this same dispersion happens even in countries and regions.

5. PREVENTIVE MEASURES

The measures that follow, in particular paragraphs 5.1 and 5.2 (Manufacturing and on site pumping and Specialisation), are primarily directed to high explosives, excluding the applicability to low explosives, such as the fuse, rock cracker and even black powder. This is because these explosive products have a specific field of application and represent, in terms of security, a much lower risk than the higher explosives.

5.1 Manufacturing and on site pumping

The manufacture of explosives can be carried out at the site of application, generally through the use of MEMU's (Mobile Explosives Manufacturing Unit), which eliminates not only the occurrence of leftovers, but also possession and transportation of such explosives, as they are directly and immediately pumped from the plant to their respective holes.

Similar results can be achieved by the use of explosive pumping units, which were manufactured in fixed installations, and then transported to places of application in tanks or IBC's and pumped through these directly into the blasting holes. In this case the transportation is not eliminated, but it is certain that the leftovers are removed.

Explosives made from MEMU's are limited to certain types of emulsions that do not meet all the needs of the explosives market and are not targeted for all types of use, due to geological reasons or the other specificities of the application sites.

Similar limitations are also associated with the application of the pumping units of bulk explosives, so these solutions, though not negligible, may not in short term be a total alternative to packaged explosives, produced in fixed units, unless unexpected and important technological developments allow it.

5.2 Specialisation

Generally, the operation of explosive application at sites (the exploitation of quarries, mines and others), can be carried out by the entities that own the site or operate the exploitation, or adjudicated to companies specialising in the application of these products. It is customary and desirable that these companies be the ones to provide the explosives, so as to reduce the entities involved, and thanks to the smaller circuit, the eventual 'predisposition to divert' the products will also be reduced.

Thus, in cases where there is subcontracting for blasting operations using explosives, the company who carries out the operation should check the debris carefully, in order to verify the possible existence of misfired explosives and take all the steps deemed necessary to detonate or neutralize them. It is, therefore, an action of great importance, in both the security and safety aspects.

5.3 Surveillance

The verification of effective implementation of explosives on site, by the supervisory entities, related to the security aspect can, in most cases lack close monitoring. These enforcement actions require a coordination between the entities involved (suppliers, users and authorities on the subject), without harming the natural unpredictability of enforcement activity. The increase of surveillance on the sites is a matter that deserves consideration and once again, any action regarding this should be taken at EU level and not at a national level.

5.4 Custody of explosives on site

The procedures taken to guard the explosives at the application sites, especially in cases where there is no storage place, should be clearly defined, including the identification of all the people who may have access to such explosives. These procedures should be subject to prior approval by the competent authorities. On the other hand, the explosive operators should only have access to the exact amounts to be used immediately.

5.5 Other Measures

The use of 'magnetic tracers' to detect misfired explosives constitutes a technological help in the application of explosives, the purpose being to detect quickly and unequivocally the existence of misfired explosives cartridges.

This detection system for misfired explosives was designed with the aim of reducing the occurrence of accidents related to undetonated explosives, but its relevance to the security aspect should not be overlooked.

Other ways to detect misfired explosives cartridges can be reached through new technologies, such as using chemical or electronic markers and the appropriated detectors systems. This is a task that is expected to find out with collaborations between manufacturers, users and competent authorities.

The use of low explosives, to deal with any secondary fragmentation (small blasting operation), can reduce the necessities of high explosives on application sites.

6. CONCLUSIONS

In the analysis made throughout this paper, about the leftovers and diversion of explosives at the application sites, showed clear evidence of the magnitude of the problem, as well as its global nature, for which we failed to find the desired miraculous formula that would finally solve the problem. Still, a set of proposals, that deserve serious consideration, were formulated to mitigate the problem.

Here are the key findings:

- There is no global approach to the problem, but there are separate measures, different from country to country, which could lose their effectiveness, due to a lack of cooperation and coordination.
- The effective traceability of explosives for civil use (expected only in 2015 by implementation of the Directive 2008/43/EC) will not solve by itself, the problem of

these products 'disappearing' from the sites of application. Additional control measures are required;

- In a certain way, the difficulty to control the explosive products held by the final user is directly proportional to the number of users involved;
- The number of final users of explosive products could be reduced drastically with the use of the expertise of companies in this field and by encouraging the manufacture and / or pumping of explosives on site;
- If the specialized companies are both the providers and users of explosive products the chain will be considerably smaller;
- We expect that technological innovations will, in a near future, allow the detection of misfires in a quick and convenient way. This will constitute a considerable advance in the safety and security aspects;
- The magnitude and consequences of the problem claim to a reflection on the possible aggravation of penalties to law breakers.

Finally, we consider that a satisfactory solution for leftover explosives cannot be achieved by an isolated provision, but by a set of measures, concerted and in a global scope, since it is a global problem.

We are well aware that we cannot close the circuit that explosives follow from manufacturing straight to usage, to reduce the risk of 'disappearance' to zero, especially when they reach the last and weakest link in the chain of trade: the end user. If an escape-proof circuit is impossible, a shorter, more controllable and safer circuit is, on the other hand, feasible and desirable.